Patterns and processes of alien plant invasions in small urban areas in South Africa:

The Berg River Catchment as a case study

Phil McLean

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Department of Botany & Zoology
Faculty of Science
Stellenbosch University

Supervisor: Prof. D.M. Richardson;

Co-supervisors: Prof. J.R.U Wilson and Dr M. Gaertner

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained within it is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated), and that I have not previously in its entirety or in part submitted this work for obtaining any qualification.

Phil McLean – October 2017

Abstract

Many studies in invasion biology focus on the negative consequences of invasive alien plant species in natural areas. In South Africa, national legislation relating to invasive species focusses mainly on the management of such species in areas that provide strategic water and/or biodiversity resources. However, urban centres are host to many alien plant species, specifically those associated with the very popular activities of gardening and the pet trade. Urban environments can facilitate plant invasions because alien plants are cultivated in large numbers and are nurtured, and there are often sites of regular disturbance that provide favourable conditions for colonisation which allow some species to become naturalized and invasive. Small urban centres are more numerous than large cities and are often more deeply embedded in the landscape. This, combined with their higher proportional perimeter-to-area ratio, means they could be launching invasions into their surrounding areas.

I investigated one such small town in detail to determine the patterns of spread of alien plant species. I then surveyed, in less detail, an additional 11 towns within the Berg River Catchment. Lastly, I compared the type and abundance of alien plant species found in towns to data on invasive alien plant species found specifically outside urban areas in the same catchment.

I found a large number of alien plant species within small urban areas, with a high proportion of listed invasives. Most of the total alien plant diversity resides in gardens, but the most abundant alien plant species in all land-use types are either listed as invasive in national legislation, or are noted as problematic species in the regional literature. The

extremely high species heterogeneity between gardens means that detailed, time-consuming surveys and high levels of taxonomic expertise are needed to ensure accurate results. However, reasonable assessments of a town's invasive plant species component can be made by surveying gardens and roadsides in low-income areas and in town centres (with the exception of the Main road, as commercial activity often render these areas hostile to plants). All urban areas surveyed were equally capable of hosting a high proportion of invasive plant species, irrespective of their location within the catchment. By comparing abundant alien plants to regional lists of invasive plant species, I was able to determine the suite urban species which have naturalization records in this catchment and have thus 'jumped the garden fence' to become invasive in the surrounding natural areas. Most species in this group were introduced for ornamental horticulture, highlighting the risks associated with this pathway.

Small urban areas are difficult to survey comprehensively due to extreme context speceficity, but contain a high diversity of alien plant species. The most abundant species are typically also naturalized, if not invasive, in the region, highlighting that small towns are important for launching plant invasions into surrounding natural areas.

Uittreksel

Binne die wetenskap van Indringer Biologie is daar baie studies wat fokus op die negatiewe impak van indringerplante op die natuurlike omgewing. Die nasionale wetgewing op indringerspesies van Suid Afrika fokus hoofsaaklik op indringerbestuur in strategiese wateropvang- gebiede en areas met hoë biodiversiteit. Stede huisves egter baie uitheemse spesies, spesifiek dié wat verband hou met tuinmaak en troeteldierhandel. Stedelike omgewings fasiliteer hierdie indringerplant verspreidings maklik, omdat uitheemse plante in groot getalle gekweek en versorg word. Daar is ook dikwels plekke met gereelde versteuring wat gunstige toestande vir kolonisering bied, dit stel sommige spesies in staat om te naturaliseer en indringers te word. Daar is meer kleiner dorpies as groot stede, en hulle is dikwels meer verweef met die landskap. In kombinasie hiermee het hul 'n hoër proporsionele omtrek-tot-area-verhouding, wat beteken dat klein dorpies die bron van infestasies kan wees. Ek het een so 'n klein dorpie in detail bestudeer om die verspreidingspatrone van uitheemse plantspesies te bepaal. Daarna het ek 11 bykomende dorpe binne die Bergrivieropvanggebied minder volledig ondersoek. En laastens het ek die soort en hoeveelheid van uitheemse plantspesies wat in dorpe gevind is, vergelyk met data oor indringerspesies wat spesifiek buite stedelike gebiede in dieselfde opvanggebied voorkom. Ek het 'n groot aantal uitheemse plantspesies gevind in klein stedelike gebiede, waarvan 'n groot persentasie reeds gelyste indringerspesies was. Tuine het die grootste hoeveelheid en diversiteit uitheemse plante, maar die mees oorheersende plantsoorte in alle grondgebruik afdelings word reeds as indringers in nasionale wetgewing gelys, of word as problematiese spesies in die streeksliteratuur beskou. Die uiters hoë spesies

heterogeniteit tussen tuine beteken dat uitheemse plantopnames in klein dorpies benodig gedetailleerde, tydrowende opnames en hoë vlakke van taksonomiese kundigheid om akkurate resultate te verseker. Redelike assessering van 'n dorp se indringerplant-komponent kan gemaak word deur ‘n opname van; tuine, padreserwes in lae-inkomste-gebiede, en in die middedorp (met die uitsondering van die hoofpad, wat gewoonlik bar is van enige plante weens kommersiële aktiwiteite). Die stedelike gebiede wat ondersoek was, het almal ‘n gelyke moontlikheid gehad om 'n hoë persentasie indringerspesies te berg, ongeag hul ligging binne die opvanggebied. Deur die volop uitheemse plante te vergelyk met streekslyste van indringerspesies, kon ek die groep stedelike spesies wat genaturaliseerde rekords in hierdie opvanggebied het, bepaal. Hulle het dus ‘ontsnap’ uit tuine om indringers in die omliggende natuurlike omgewing te word. Die meeste spesies in hierdie groep is bekend as sierplante vir tuinbou, wat dan ook die risiko’s verbonde aan hierdie roete van verspreiding beklemtoon.

As ‘n gevolg van uiterste konteks-spesifisiteit, is dit moeilik om volledige opnames in klein stedelike gebiede te maak, maar dit bevat 'n hoë diversiteit van uitheemse plante. Die volopste spesies is tipies ook genaturaliseerd, of reeds ‘n indringer in die streek, en beklemtoon die feit dat klein dorpies ‘n belangrike faktor is vir die verspreiding van indringerplante in die omliggende natuurgebiede.

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General introduction:

Species of animals and plants have been moved by humans all over the world. This has been done both deliberately for agriculture, horticulture and the pet trade, but also unintentionally through stowaways and contaminants (Hulme et al. 2008; Mack 2003; Faulkner et al. 2015). In the terminology elucidated by Blackburn et al. (2011) and Richardson et al. (2011b), these species are 'alien' in the new environments to which humans have relocated them. A small subset of those species which manage to survive in these novel environments, are able to overcome barriers to their reproduction (e.g. find suitable mates, thus becoming 'naturalised') and spread (finding new environments to colonise, often considerable distances from their initial point of introduction) and can thus become 'invasive' (Blackburn et al. 2011). Many invasive species have negative impacts in the environments to which they have been introduced. Such negative impacts include causing the extinction of other species (Clavero and García-Berthou 2005) and impacting ecosystem services such as reducing the supply of water (Le Maitre et al. 1996).The costs of dealing with or remediating these impacts can be very high (Pimentel et al. 2000).

Horticulture is a major global pathway for the introduction of plant species (Hodkinson and Thompson 1997; Reichard and White 2001; Dehnen-Schmutz et al. 2007a,b; Foxcroft et al. 2008), and is probably responsible for the strong positive correlation between human population density and alien plant species richness (Aronson et al. 2014a; Aronson et al. 2014b). The horticultural trade, by its very nature, overcomes the first barrier in the introduction-naturalization-invasion continuum, as plants are sourced and moved over considerable distances across the world. In these new locations, these alien plant species are often nurtured and their survival encouraged by enthusiastic gardeners intent on looking after their floral investment (unlike stowaways, for example, which must immediately adapt to new conditions and environments if they are to persist). Gardeners typically alter or control edaphic factors like soil fertility, acidity and (seasonal) moisture content to suit the species or suite of species they are attempting to cultivate.

Some of the characteristics that make for an appealing horticultural specimen are the same as those which are of concern to invasion biologists, namely vegetative reproduction, drought tolerance, being able to re-sprout and prolific flowering and/or fruiting (Marco et al. 2010).

Many studies from a diversity of locations around the world have demonstrated the importance of the horticultural trade in encouraging a preference for alien plant species over indigenous plants within gardens (Reichard and White 2001; Lubbe et al. 2011; Ööpik et al. 2013; Cubino et al. 2015). Propagule pressure is also increased since some species are repeatedly introduced in large numbers through this pathway over time (Hodkinson and Thompson 1997; Zenni 2014). This introduction trend is likely exacerbated by the recent rise in internet trade which makes many more species potentially available to prospective buyers (Lenda et al. 2014).

Despite the scale of introductions of alien plants into urban areas through the horticultural trade, many potentially invasive species have not yet spread. There are thus high levels of invasion debt (*sensu* Rouget et al. 2016): even if no new species are introduced, many that are already planted will become invasive in the future (Downey and Glanznig 2006; Asmus and Rapson 2014; Cubino et al. 2015).

Plants introduced for horticulture are usually introduced to urban areas first, but they are sometimes able to spread from urban areas into surrounding natural and semi-natural environments since these are often highly disturbed, providing opportunities for recruitment (Alston and Richardson 2006) - the so-called weed-shaped hole (Buckley et al. 2007). Similarly, human movements within and out of urban spaces facilitate the dispersal of propagules to the surrounding natural areas, particularly seeds which can be transported an appreciable distance by cars (Zwaenepoel et al. 2006; von der Lippe et al. 2013). This means that urban centres can act as sources for the launching of invasions into surrounding areas (Alston and Richardson 2006; von der Lippe and Kowarik 2008; Marco et al. 2010).

Cities are concentrations of urbanisation which display dense human habitation. They typically have many ports of trade and possible entry as well as gardens; they thus often have much greater alien plant species richness than rural towns and are often also the first places in a country to which a plant is introduced (Pyšek 1998; Vitousek et al. 1997a,b; Dodd et al. 2016; Padayachee et al. 2017). Added to this is the fact that urbanisation is increasing in all regions of the world. More than half the global human population now lives in cities and towns (United Nations 2016), and this trend is likely to increase (Grimm et al. 2008), concomitantly increasing the risks of further introductions.

Most research on alien and invasive components of urban flora has focussed on big cities (e.g. Alston and Richardson 2006; Lambdon et al. 2008; Botham et al. 2009; Aronson et al. 2014b; Lenda et al. 2014). However, it could be argued that small urban centres (hereinafter referred to as 'towns') present a greater risk to their surrounding environments than large cites. Small towns have a large edge-to-area ratio, meaning that most areas of the town are proportionately close to the surrounding natural areas (Marco et al. 2008). Marco et al. (2010) showed how plants on the peripheries of gardens were more likely to escape into the surrounding semi-natural areas. Hence the relative distance to the urban/wildland interface (Alston and Richardson 2006) is low for all gardens in a small town (as opposed to ones in a city, which may be several kilometres from natural areas). In addition, small towns are significantly more numerous than cities meaning their cumulative impact could be substantial.

In South Africa, national legislation recognises the threat posed by invasive species and all landowners have a 'duty of care' to control invasive species on property under their control. The *National Environmental Management: Biodiversity Act* (NEM:BA; Act 10 of 2004; DEA 2014) compels "all organs of state in all spheres of government", including municipalities, to deal with invasive species by "preparing an invasive species monitoring, control and eradication plan for land under their control" (NEM:BA 2004). This plan must be compiled according to Section 76.(2)(a) of NEM:BA and should form part of each municipality's integrated development plan (IDP). Such a plan must include [76(4)(a-f)]:

a) detailed lists and descriptions of listed invasives;

b) a description of the parts of land infested;

c) an assessment of the extent of each infestation;

d) a status report on the efficacy of (any) previous control measures;

e) current measures to monitor, control and eradicate invasives;

f) measurable indicators of progress and success of above control measures (including a timeline of projected completion).

Plans must include land under urban settlement within each municipality's jurisdiction.

Currently, there is a serious lack of capacity across the majority of municipalities in South Africa to comply with this act (Irlich et al. 2017). This means that small towns warrant study on an international scale, but also specifically within the South African context in order to better understand the dynamics behind their alien and invasive flora components and the likelihood of these being the front for further invasion into natural environments on their borders.

This thesis, therefore aimed to explore the factors determining the number and distribution of alien plant species in small towns; assess which alien urban plants have become invasive; and whether there is any evidence for alien plant species spreading from towns into surrounding natural areas. These questions on location and spread are scale-dependant, so this thesis comprised of three studies, each at a different scale. These independent, but linked studies, set out to investigate the patterns and extent of spread of alien and invasive plant species in small towns from the same geographic region. See Fig. i. for a graphic representation of the research questions across different scales that this body of work attempted to answer, broken down by chapter in the thesis.

My aims were to understand patterns of distribution of both alien and invasive alien plant species within small towns and use this to determine whether there was a method to rapidly, but reasonably accurately, survey small towns to assess their alien and invasive plant species components. I was also interested to determine whether any patterns of distribution could be detected which could assist municipal managers in South Africa in their efforts to comply with national legislation and to control these problematic species within urban spaces under their jurisdiction. Lastly, I considered it important to contextualise this urban invasive species load in relation to its potential impact on surrounding natural areas. Given the differences that exist between the human-manipulated microclimatic and edaphic conditions inside towns and those in the surrounding landscape, I wanted to establish whether any alien plant species within towns posed a risk to their surrounding environments. In other words, do plants that spread within towns also spread into the natural systems beyond the urban fringe? And, if so, how does one decide which species to prioritize for management?

To accomplish these aims at increasing scales across the landscape, my first undertaking was a very detailed inventory of alien plants within one small town in the Western Cape province of South Africa (Fig. i.). The survey was also designed to determine the introduction status of the alien plant species observed (i.e. how far along the introduction-naturalization-invasion continuum they were, after Blackburn et al. (2011)). In an effort to develop recommendations for monitoring, I also investigated search effort versus accuracy to test several potential sampling strategies.

Secondly, I developed a protocol for urban plant surveys, and applied this to eleven additional small towns within the same biogeographical region (using the Berg River catchment as a study area). Here I investigated patterns in location of alien and invasive plants within small towns.

The Berg River catchment contains several declared protected natural areas and is part of the strategic water supply for the region (especially the large metropolitan city of Cape Town). Consequently, there is a wealth of information relating to plant invasions within natural areas beyond the urban centres with which to compare my urban-specific plant survey data. This comparison informed the third part of this study where the potential future regional risk posed by urban alien flora was investigated.

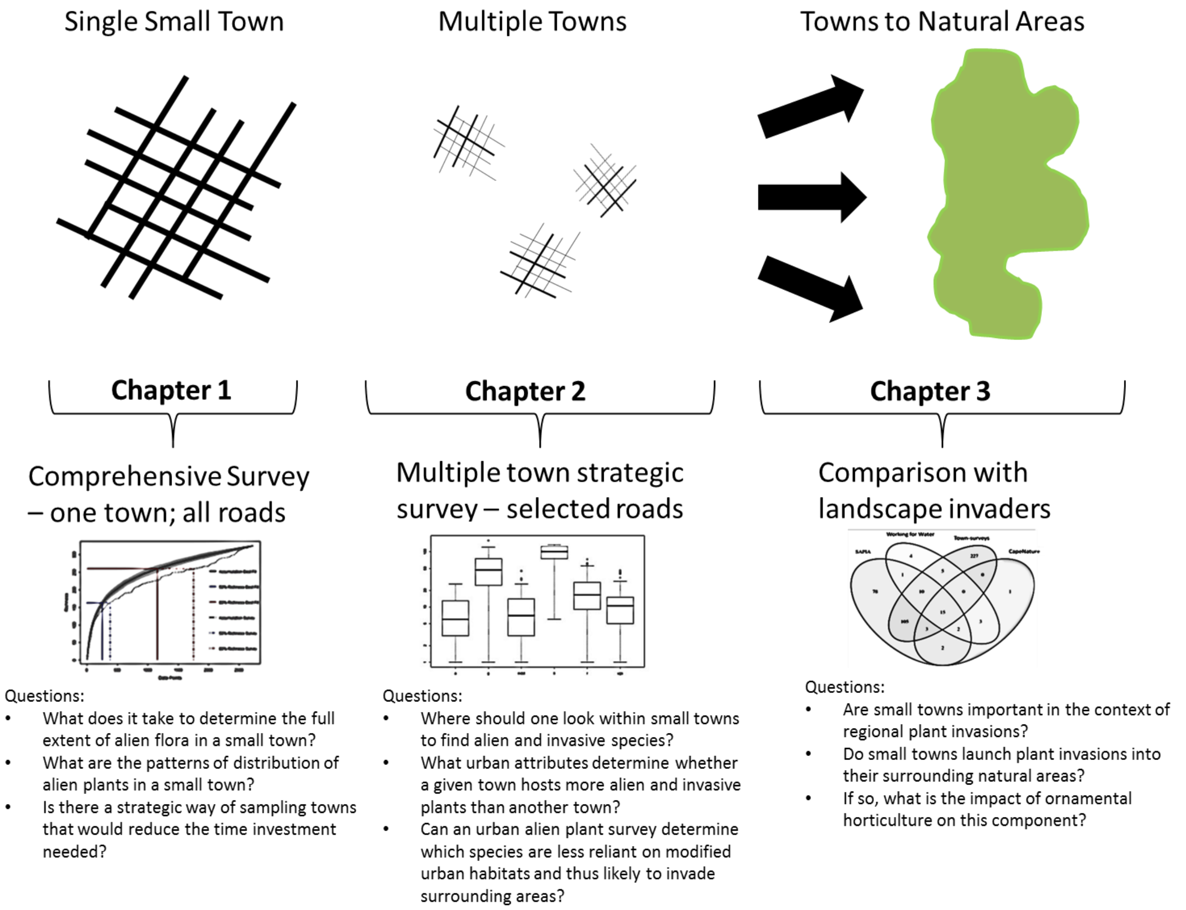

Fig. i.: Visual representation of the geographical scale and main questions for each chapter of this thesis including a representation of the main results output for each. Chapter 1 found that urban alien plant surveys require a high degree of search effort, principally due to heterogeneity between gardens. Chapter 2 found that most alien and invasive plant species are located within low-income areas and town centres (excluding the main commercial road). Chapter 3 reported that small towns are capable of launching plant invasions into surrounding natural areas.

Chapter synopses:

The following section provides a short synopsis on the focus of each chapter and where it was published or submitted.

Chapter 1: The distribution and status of alien plants in a small South African town

This chapter was submitted to the *South African Journal of Botany* and is currently under review.

For this Chapter, I conducted a detailed survey of all alien plant species occurring within the small urban centre of Riebeek Kasteel noting their abundance, location according to land use type, and indications of their ability to naturalize and/or spread within this space. The search effort required for the survey was considerable, both in terms of time and also taxonomic expertise required. I found a high diversity of alien plant species, over 80 % of which were contained in gardens. A high proportion of species encountered are already listed under the National Environmental Management: Biodiversity Act (NEM:BA) or are noted as spreading in local literature. Species accumulation curves indicated that, due to the diversity between gardens, any reduction in search effort reduces the confidence level of the results.

Chapter 2: A method for the rapid assessment of invasive alien plants in small urban centres: South Africa's Berg River catchment as a test case

This chapter is intended for submission to *Bothalia: African Biodiversity & Conservation*

I developed an urban-specific alien plant survey methodology and applied it to 11 small towns within the Berg River catchment. As with the preceding chapter, I also noted abundance by land-use type, but included low-income areas as a discreet land-use type. I investigated relationships between the number of alien plant species found within these urban areas to potentially explanatory variables; notably population density, road network, and age of town. Interestingly, only road network extent was significantly correlated. I then compared the distributions according to land-use type and road type of 1) all alien plant species and 2) invasive plant species (those also recorded in the regional naturalization database, SAPIA) for all the towns surveyed. Results indicate that low-income areas of small towns have a higher proportion of invasive species than other land-use types or road types, and confirm results of Chapter 1 in that the majority of alien and invasive plant species diversity in small towns is contained in gardens. Despite gardens within a given town being heterogeneous, there was strong homogenization of urban alien flora across the catchment.

Chapter 3: Small urban centres as launching sites for plant invasions in natural areas: insights from South Africa

Reference: McLean, P., Gallien, L., Wilson, J. R. U., Gaertner, M., Richardson, D. M. 2017. Small urban centres as launching sites for plant invasions in natural areas: insights from South Africa. *Biological Invasions.*

For Chapter 3, I compared the urban alien plant data from the surveys for the previous chapter to datasets of alien plant species for natural (non-urban) areas in the catchment. These datasets were compiled from Working for Water (WfW) clearing data (including several NGO's who act as implementing agents for WfW as well as the South African National Biodiversity Institute's invasive species data), CapeNature conservation agency data and records from the Southern African Plant Invader Atlas (SAPIA). The data showed a number of alien plants found abundantly in small urban areas which are also recorded as invasive in the region. More importantly, results indicated a large number of species occurring in towns are naturalized but not currently managed or controlled in the surrounding areas. This implies very high invasion debt even for the fairly harsh environmental conditions experienced outside the relative safety of urban cultivation. The likelihood of plants being recorded as naturalized increased with their abundance in towns and if they were tall and woody (characteristics which define the worst current landscape-level invaders). We conclude that small towns can act as launching sites for plant invasions into the surrounding environments and use our data to predict which species might be exiting the lag phase on the invasion continuum thus representing the next wave of potential invaders in the region.

Chapter 1:

The distribution and status of alien plants in a small South African town

This chapter was submitted to the *South African Journal of Botany* and is currently in review.

Authors: Phil McLean[1,2], John R.U. Wilson[1,2], Mirijam Gaertner[1,3] Suzaan Kritzinger-Klopper[1] and David M. Richardson [1]

Address: [1] Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.
[2]South African National Biodiversity Institute, Kirstenbosch National Botanical Gardens, Private Bag X7, Claremont 7735, South Africa.
[3] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

Contribution of each author:
PM, DMR, JRUW & MG: Planning and design of the study.
PM: Conducted fieldwork, species identification, statistical analyses, and led the writing.
DMR: Commented on the manuscript and improved the writing.
JRUW: Commented on the manuscript and provided statistical advice.
MG: Commented on the manuscript.
SK-K: Provided fieldwork planning and assistance and commented on the manuscript.

Abstract

The invasion of alien plants into natural ecosystems in South Africa is a substantial conservation concern. The primary reason for the introduction of alien plants has been ornamental horticulture, and urban centres are the main sources of invasions. Small towns have high edge: area ratios, which favours the launching of invasions into surrounding areas. There is, however, a shortage of information at the global or local scale on the occurrence, distribution, and status of alien plants in an urban context.

We surveyed all alien plants in the small town of Riebeek Kasteel in the Western Cape, South Africa, to gain insights on where to find alien plant species, and to assist with future studies and the management of alien floras in small towns.

We surveyed publically accessible land, recording the abundance of all alien plant species every 10 m. A species accumulation curve was compiled to show the rate at which new species were encountered. This approach was used to test the efficacy of different sampling strategies.

Two hundred and ninety eight alien plant taxa were recorded in five land-use types. Half of the alien plant species recorded were naturalized within the town, while a third were invasive in the region (the Berg River catchment). 95% of the taxa, including many invasive species, occurred in gardens or adjoining road-sides, highlighting the invasion risk posed by horticulture. The most efficient way of collecting data on alien plant distribution for this town would have been to survey roads in the town centre first, rather than urban-edge roads and industrial areas.

Synthesis and applications: The gardens of small towns in South Africa harbour a high diversity of alien plants, many of which are already invasive or are potentially invasive. Context dependence means it is difficult to extrapolate generalised rules of thumb on where to survey. This means that compiling accurate inventories of alien plants in urban areas requires substantial search effort and taxonomic expertise.

1.1 Introduction

Alien plant invasions are a major conservation concern in many parts of the world (Mack et al. 2000), including South Africa (Richardson et al. 2011a). Urban areas are hotspots for the introduction of alien plant species (Pyšek 1998; Vitousek et al. 1997a), particularly of plants used for ornamental horticulture (Reichard and White 2001; Sanz-Elorza et al. 2008; Marco et al. 2010; Asmus and Rapson 2014). It is therefore not surprising that there is a strong correlation between human population density and alien plant species richness (Spear et al. 2013; Aronson et al. 2014a; Aronson et al. 2014b). Urbanisation is increasing in all regions of the world, and more than half the global human population now lives in cities and towns (United Nations 2016). This trend is likely to increase into the future (Grimm et al. 2008). While increasing urbanisation is likely to exacerbate problems associated with cities as sources of alien propagules, historical patterns and processes mean that there is already a large invasion debt: even without further introductions, many species that are already introduced will become invasive over time (Rouget et al. 2016).

Despite these findings and the obvious risks, few studies have examined the structure and patterns of alien plants within urban spaces. Those that have been done have focussed on large cities (e.g. Alston and Richardson 2006; Lambdon et al. 2008; Botham et al. 2009; Aronson et al. 2014b; Garcillán 2014; Lenda et al. 2014). While large cities typically have more alien plant species than small rural towns and villages, and are often the first places in a country to which a plant is introduced, smaller towns typically have a relatively larger urban-wildland interface (a notable exception is the City of Cape Town with the Table Mountain National Park embedded within its boundaries). A large urban-wildlife interface means that established urban alien plant species with expanding populations only need to cover a relatively small geographical distance before reaching surrounding natural areas (Moreira-Arce et al. 2014). This effect was also noted by Marco et al. (2010) who observed that species planted on garden margins were more likely to escape into adjacent areas. Smaller towns are also much more numerous than big cities and so collectively represent a higher risk of contributing invasive propagules into the surrounding areas.

South Africa has enacted national legislation aimed at controlling invasive species which has implications for the urban environment (Box 1).

Box 1: South African legislation dealing with alien and invasive species

The National Environmental Management: Biodiversity Act (NEM:BA, Act 10 of 2004) compels “all organs of state in all spheres of government”, including municipalities, to deal with invasive species by “preparing an invasive species monitoring, control and eradication plan for land under their control” (DEA 2014). This plan must be compiled according to Section 76.(2)(a) of NEM:BA and should form part of each municipality’s integrated development plan. Such a plan must include [76(4)(a-f)]:

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d) a status report on the efficacy of (any) previous control measures;

e) current measures to monitor, control and eradicate invasives;

f) measurable indicators of progress and success of above control measures (including a timeline of projected completion).

Plans must include the land under urban settlement within each municipality’s jurisdiction. The results of the research presented in this paper will be useful to municipalities with regard to their NEM:BA compliance.

However, most municipalities do not have the capacity to service the requirements of NEM:BA (Irlich et al. 2017). While some information is available at a broad environmental scale on the existence and general location of alien plant species outside of cultivation that will assist municipalities in compiling their plans (Henderson and Wilson 2017), there is very little information on the location, identity, and distribution of alien plants in the urban spaces in the country.

We hypothesised that there would be differences in the occurance and abundance of alien plant species according to different land use types within the town. Our aims were thus to systematically map the occurrence and abundance of alien plants in a small town in South Africa, and, based on the data collected, to propose a strategic approach to guide future surveys of alien plants in small towns in South Africa. The survey strategy developed here could be used to help municipalities to meet their regulatory requirement to report on the occurrence of invasive species in urban areas. We also aimed to determine the introduction status of alien plants captured in our survey. Such information can assist managers in the identification and prioritisation of invasive species within the urban context.

1.2 Methods

1.2.1 Site description

Riebeek Kasteel is a small town of 6.9 km^2 situated within the Swartland Municipality (part of the West Coast District Municipality) in the Western Cape, South Africa (Fig. 1.1.; see also Fig. 2.1.). The town was established in the 1860s and it currently has a population of 1144 people at a density of 179 persons/km^2 (StatsSA 2016). The town has a mixture of residential, industrial, commercial and agricultural land uses and is bordered mainly by agricultural land (primarily vineyards) and in the west by natural vegetation of the Riebeek Kasteel Mountain and the Kasteelberg Nature Reserve. Its relatively long history and diversity of land-use types makes Riebeek Kasteel an ideal subject to investigate the patterns of distributions of alien plants in a small urban centre. In terms of its size and complement of alien plants Riebeek Kasteel is typical of towns in the Breede River catchment (McLean et al. in 2017).

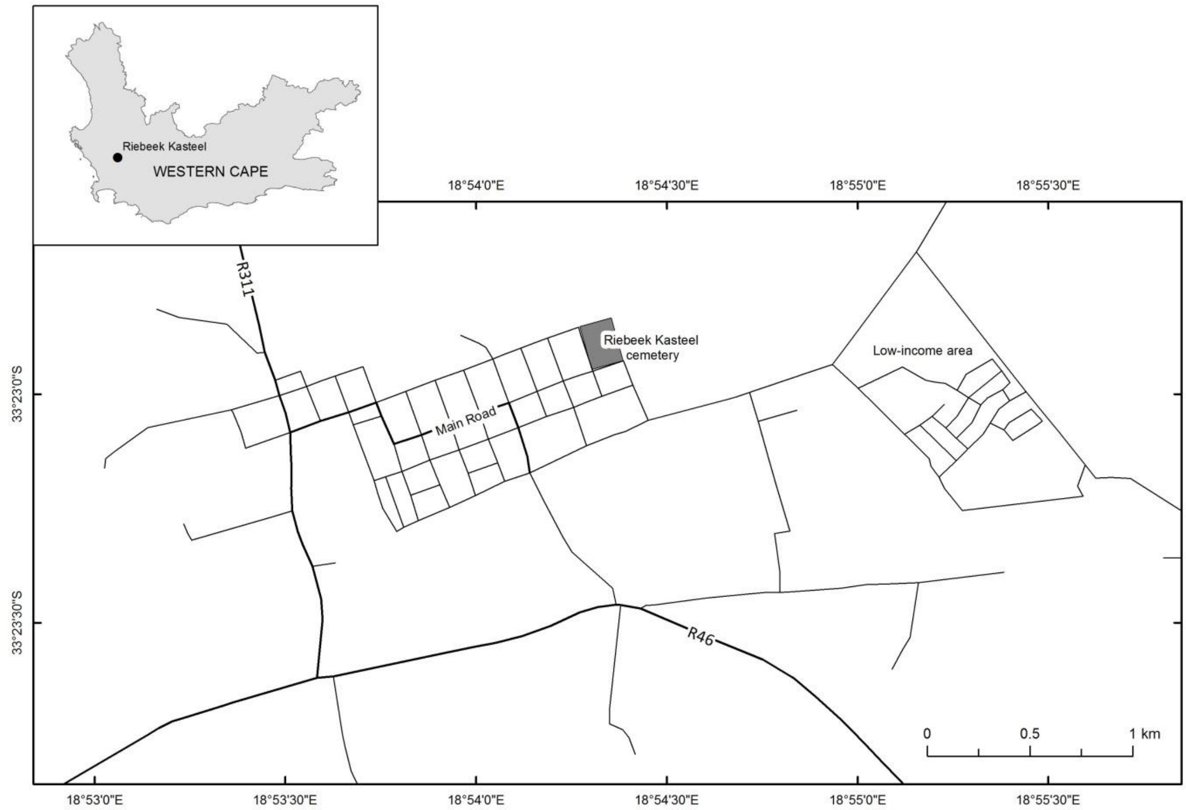


Fig. 1.1. Location of Riebeek Kasteel within the Western Cape province of South Africa. Detail shows the town's basic roadmap indicating the main road through the town, the low-income area, and the cemetery.

1.2.2 Field-Survey

We treated roads in the town as transects for our survey and sampled all publically accessible roads in the town. While we covered all such roads over the course of the study, we were not prescriptive in our choice of routes that we took during the survey (i.e. roads were not selected strategically, but haphazardly). This survey was undertaken by the same two observers (PM and SK-K) over eleven non-consecutive days in the spring of 2015 (August-October). While it is possible that a few additional plants might have been found if we had sampled in other seasons, the vast majority of plants in the area flower and/or have foliage in spring. We walked each public road taking a GPS waypoint every 10 m. This was done for both sides of each road because it was not feasible to accurately identify or count individuals on the far side of roads given the distance and the increased potential of obstructions between the viewer and the specimens. At each waypoint we recorded the identity and number of each alien plant species visible within three observation zones. The observation zones were: 1) within a radius of 1 m of the observer; 2) within a radius of 10 m (until the next observation point or into a garden/property up until the view was obstructed by a tall building); 3) plants appearing above or behind visual obstructions like buildings which would not likely be captured from another street (the datasheet used for this survey is shown in Supplementary Table 1.1). Species recorded at one waypoint were not included at the next waypoint to avoid double counting, while species more than 15 m distant beyond the edge of town were also not recorded. This methodology enabled us to extend the sampling range of each point to capture information on plants which may be located relatively far from the road (e.g. back gardens).

Numbers of individuals of all taxa observed were calculated as number of stems for large, woody species, and as the estimated canopy cover (in m^2) for herbaceous or spreading/creeping species.

We also noted points where no species could be observed (for example when standing on a paved driveway and where anything visible in Zones 2 or 3 would be captured by the next or previous observation waypoint). The growth stage of individuals was recorded at each waypoint as either ‘adult’ (ideally there was evidence of flowering or fruiting, but occasionally plants were coded as adults simply on the basis of their size), or ’seedling’ or ‘young, non-reproductive individual’. A measure of the degree of cultivation at each sampling point was taken as either high (well-tended gardens and mowed open areas like parks and playgrounds); medium (less-well maintained gardens and public open spaces); or low (obviously unmanaged areas). Whether an individual plant was purposefully planted or naturally recruiting was noted and we attempted to determine whether the species had the opportunity to recruit at each sampling point (was it on open, fertile ground, or embedded within paving, for example) and whether there was evidence of recruitment (i.e. the presence of unplanted propagules in the vicinity). The land-use type was also recorded at each waypoint for each observation zone according to five categories: Agricultural land; Garden; Roadside/Curb (whether bordering garden or agricultural land); Urban Green Space (we used an adaptation of the definition used by Cilliers et al. (2012) which includes publically accessible spaces within the town, whether formally gardened or not including parks, churches and open plots); and Industrial (including sites of heavy industry, warehouses, commercial space and the waste water treatment works). Lastly, we included field-notes, e.g. that some roadside plants appeared to have grown from dumped garden waste.

While we limited our survey to publically accessible roads, most properties in the town had either no perimeter walls or only low ones, which effectively gave visual access to most species growing in private gardens.

In some cases, identification to species level was not possible in the field, in which case a photograph and/or a physical sample (if possible) were taken. These were later sent to a taxonomist for identification. Species names were cross-checked for synonymy using The Plant List (Version 1.1, 2016; accessed January 2016) or the advice of taxonomists. Some individuals of the genera *Cupressus, Eucalyptus, Melaleuca* (including *Callistemon*) and *Pinus* require close-up examination for positive identification to species or subspecies level. This is because of subtle variations in leaves, bark, fruit or flower morphology. Most surveyed land was privately owned and thus direct access was not always possible, which prevented the close scrutiny required for species-level identification for some individuals. Analyses were thus done at the genus level for these groups of plants to avoid any representational biases.

Terminology in this paper follows the definitions proposed in Blackburn et al. (2011) and Richardson et al. (2011b). Taxa were thus classified as 'alien' if their presence in the region is the result of human actions. Those alien taxa that overcome reproductive barriers such that they can produce multi-generational, self-replicating populations without human assistance (or despite human intervention) are termed 'naturalized'. Some naturalized species are able to produce large numbers of reproductive offspring which have the potential to disperse over long distances. When this happens far from sites of initial introduction, the taxa were categorized as 'invasive'.

1.2.3 Analysis of alien plant distribution by land-use type

To examine patterns in the distribution of alien plants according to land-use type, we first tested for unequal variances using Welch's Test before running a pairwise, post-hoc Tukey T-test to test for significant differences. The same tests were also applied for the abundance of alien plant species found within each land-use type. For this analysis of abundance, we took the measure of 1 m^2 of spreading plants as equal to one individual plant for those growth forms where this could be easily counted so that their numbers could be compared to those of the woody species. We then tabulated the 20 most abundant plant species in each land-use type for comparative analysis.

1.2.4 Model to determine optimal search-strategy

We analysed the rate of species accumulation by using the specaccum function in R 3.3.1 (vegan package; Oksanen et al. 2013). We ran the package using the data as it was sampled in the survey, then again using the package's default setting which samples all sites in random order to generate a baseline and target data accumulation rates. On these curves we calculated the number of data points it would take to capture 80 % of the total species pool.

Sampling random points is not sensible in practice, as it would be difficult to do, and would potentially take more effort (relocating across town at random whilst trying to ensure all possible data points were captured and without duplicating entries). So we had to consider other approaches to sample the town strategically to capture the greatest amount of data for the least effort. Our first approach was to consider those locations which had the highest number of species per data point. We plotted this data using the Kernel Density tool in Spatial Analyst ArcMap 10.4 (ESRI 2015; see Supplementary Fig 1.1). This allowed us to return to the data and re-run the species accumulation curve based on decreasing species density patterns.

When this approach did not result in a significantly more rapid accumulation of data than our original, haphazard survey method, we considered another series of strategies based on the systematic sequential sampling of particular roads within the town. For this approach, data were coded according to their location on different discreet road types within the town. We defined seven road types from our transect data: Main road = the main commercial route through the town; Access roads = arterial roads linking the town to major roads in the region; Urban edge roads = those roads characterised by a single erf directly exposed to areas outside of the town (i.e. not adjacent to another garden); Perpendicular roads = roads running perpendicular to the town's main road; Parallel roads = roads running perpendicular to the town's Main road; Industrial areas = roads defined by industrial activity (e.g. waste-water treatment works, industrial/manufacturing zones, electricity sub-stations); and Low-income areas = Roads in low-income areas. We defined "low-income areas" as those portions of the town which were the result of racial and economic separation under apartheid legislation before 1994 (see Shackleton and Blair, 2013 and McConnachie and Shackleton, 2010).

To devise and compare strategies for rapidly accumulating species richness using sequences of the different road types, we first generated a table of all the possible road combinations from the seven categories described above. Each road type's species richness data consisted of a matrix of presence/absence data for that road type for all the alien plant species observed in the town. We could then test sequential combinations of road types to see which new road types added the most novel species to the cumulative richness for the group. This was repeated for all levels of combinations (e.g. choosing just a single road type; choosing two road types; choosing three road types; etc.). For each level, we noted the best combination's proportion of the total species count and the effort required to reach this number (as a proportion of the total data points required) (see Table 1.3).

1.2.5 Introduction status assessment

We were also interested to determine the introduction status of all alien plant species encountered in the town using categories as defined in the Unified Framework on Biological Invasions (Blackburn et al. 2011) (Table 1.5). To do this we filtered the results of species occurrence by the metrics of whether they were purposefully planted by humans or whether they were recruiting without assistance (i.e. All 'Alien' species were split into

Naturalized or Not Naturalized). To determine which species were spreading "in the wild" and thus Invasive outside this urban setting, we referred to the regional literature on invasive and problematic plant species (Henderson 2001; Bromilow 2010), and plotted the abundance records of this set to indicate the most successful species within this group.

1.3 Results

1.3.1 Sampling effort

We sampled 7807 waypoints throughout Riebeek Kasteel covering a distance of c. 60 km. The survey took 11 days to complete, but because on some days two researchers were working simultaneously in the field, the survey required 16 person-days in total. We found 298 species of alien plants in the town of which 98 (33 %) are listed as invasive under South African legislation (NEM:BA)(see Appendix A for a full list of alien plant species recorded during this survey).

1.3.2 Distribution

The diversity of alien plant species encountered per land-use type differed significantly (Welch = 42.294, d.f. = 4, P<0.001) as did the abundance of plants (Welch = 9.572, d.f. =4, P<0.001). Most species were found in Gardens; this land-use type contained 84 % of all species recorded (Table 1.1). Species diversity in Gardens was significantly different (P<0.001) from Curbs, Urban Green Spaces and Agricultural areas and different (P<0.05) from Industrial areas. Gardens also had the highest number of data points, however, meaning the average number of species per data point was the lowest for any land-use type measured (0.06, Table 1.1). So greater search effort is required to gain the species richness contained in this land-use set. While Agricultural and Industrial areas have more species per data point on average (0.14 and 0.18 respectively), these land-use types had very low overall species richness (15 % and 29 % respectively). Gardens were also noteworthy in having a very high range of species per data point, (between 0 and 20); with their maximum being 40 % higher than the next highest (Curbs, at 12 species per data point).

Table 1.1: The distribution of species richness and abundance of alien plants observed across five land-use types within the small town of Riebeek Kasteel, South Africa. Parentheses for number of species and abundance of plants rows show the proportion that land-use type contributes to the total for that metric (and are thus not additive). The number of data points that were captured for each land-use type is also shown as is the average number of species encountered per data point for each land-use type. We also included in parentheses the range of species number recorded per data point for each land-use type. Abundance of plants is measured as the total number of individuals counted.

	Agricultural	**Garden**	**Industrial**	**Curbs**	**Urban Green Space**	**Total**
Total number of species	46 (15 %)	249 (84 %)	85 (29 %)	196 (66 %)	93 (31 %)	298
Abundance of plants	92,809 (70 %)	13,278 (10 %)	3,335 (3 %)	8,588 (6 %)	14,791 (11 %)	132,799
Data points	329	3997	453	1754	867	7400
Average number of species per data point	0.14 (0-7)	0.06 (0-20)	0.18 (0-8)	0.11 (0-12)	0.11 (0-11)	

The lowest proportion of species to total was recorded in Agricultural areas (only 46 species out of the total of 298), but these areas accounted for the greatest abundance of plants. Industrial land-use and Urban Green Spaces had moderate representations of total species diversity but abundance was very low for plants in Industrial spaces (3 %).

When considering the most abundantly occurring plants within each land-use type, it was evident how many are listed as invasive under national legislation or within literature for problem plants in the region (Table 1.2). Industrial areas and Urban Green Spaces had only one and two plants respectively within the top 20 most abundant species that were not problematic plants or listed invasives. Problematic plants or listed invasive species account for the majority (78 %) of the most abundant plants for all land-use types.

Table 1.2: The top 20 species by abundance in each land-use type in the small town of Riebeek Kasteel, Western Cape, South Africa. Species listed under national legislation as invasive are shown in **bold underlined** type and problematic plants but not listed species or those listed elsewhere in the country are indicated with an *.

Agricultural	Garden	Industrial	Curbs	Urban Green Space
Vitis vinifera	*Syzygium paniculatum**	***Acacia saligna***	*Vitis vinifera*	*Pennisetum clandestinum**
*Avena fatua**	*Rosa* sp.	***Echium plantagineum***	*Avena fatua**	*Avena fatua**
Echium plantagineum	*Pennisetum clandestinum**	*Avena fatua**	*Pennisetum clandestinum**	***Echium plantagineum***
Vicia benghalensis	*Duranta erecta**	*Trifolium angustifolium**	***Agave americana subsp. americana var. americana***	***Eucalyptus* sp.**
Cypress	*Olea europaea subsp. europaea*	*Duranta erecta**	***Arundo donax***	***Arundo donax***
Olea europaea subsp. europaea	*Bougainvillia*	*Raphanus raphanistrum**	*Erodium moschatum**	*Cotula turbinata**
Melia azedarach	Cypress	***Ricinus communis var. communis***	*Rosa sp.*	*Briza maxima**
Acacia saligna	***Schinus terebinthifolus***	*Pennisetum clandestinum**	*Bougainvillia*	*Erodium moschatum**
Casuarina cunninghamiana	***Arundo donax***	*Urtica urens**	*Syzygium paniculatum**	***Acacia saligna***
*Briza maxima**	***Agave sisalana***	*Erodium moschatum**	*Bryophyllum fedtschenkoi*	*Vicia sativa subsp. sativa**
*Foeniculum vulgare**	***Agave americana subsp. americana var. americana***	*Malva parviflora**	***Echium plantagineum***	*Raphanus raphanistrum**
Xanthium strumarium	***Casuarina cunninghamiana***	***Catharanthus roseus***	***Pennisetum setaceum***	***Acacia pycnantha***
*Raphanus raphanistrum**	***Melia azedarach***	*Solanum nigrum**	***Catharanthus roseus***	***Sesbania punicea***
*Erodium moschatum**	***Myoporum tenuifolium***	*Persicaria lapathifolia**	*Hypochaeris radicata**	*Quercus robur*
*Pennisetum clandestinum**	*Populus nigra var. italica**	*Olea europaea subsp. europaea*	***Agave sisalana***	*Tropaeolum majus**
*Cotula turbinata**	*Agave attenuata*	*Cynodon dactylon**	***Casuarina cunninghamiana***	*Olea europaea subsp. europaea*
Ficus carica	***Catharanthus roseus***	*Syzygium paniculatum**	***Hakea salicifolia***	***Vicia benghalensis***
Lavandula sp.	*Papaver* sp.	***Acer negundo***	*Gaura lindheimeri*	***Ricinus communis var. communis***
*Solanum nigrum**	*Syagrus romanzoffiana*	***Melia azedarach***	*Cypress*	***Agave sisalana***
Ricinus communis var. communis	***Canna indica***	*Cotula turbinata**	***Populus x canescens***	***Casuarina cunninghamiana***

1.3.3 Sampling strategy models

Figure 1.2 shows the species accumulation curve based on the field-survey. This resulted in 80 % of the total species being captured after 1756 data points (out of a total of 2742; or 64 % effort). It also indicates a fairly steady accumulation of novel species for increasing sampling effort, i.e. there was no obvious flattening off of the curve to indicate saturation of species diversity as the survey progressed. According to this graph, roughly 20 novel species were found per day at a fairly consistent rate after the initial 2 days of survey. If our survey had selected random points throughout the town until all possible points were sampled, it would have resulted in a more rapid accumulation of species richness than our field-survey (as indicated by the default curve drawn by the speccacum function; Fig. 1.2.). However this strategy would be unrealistic and time consuming.

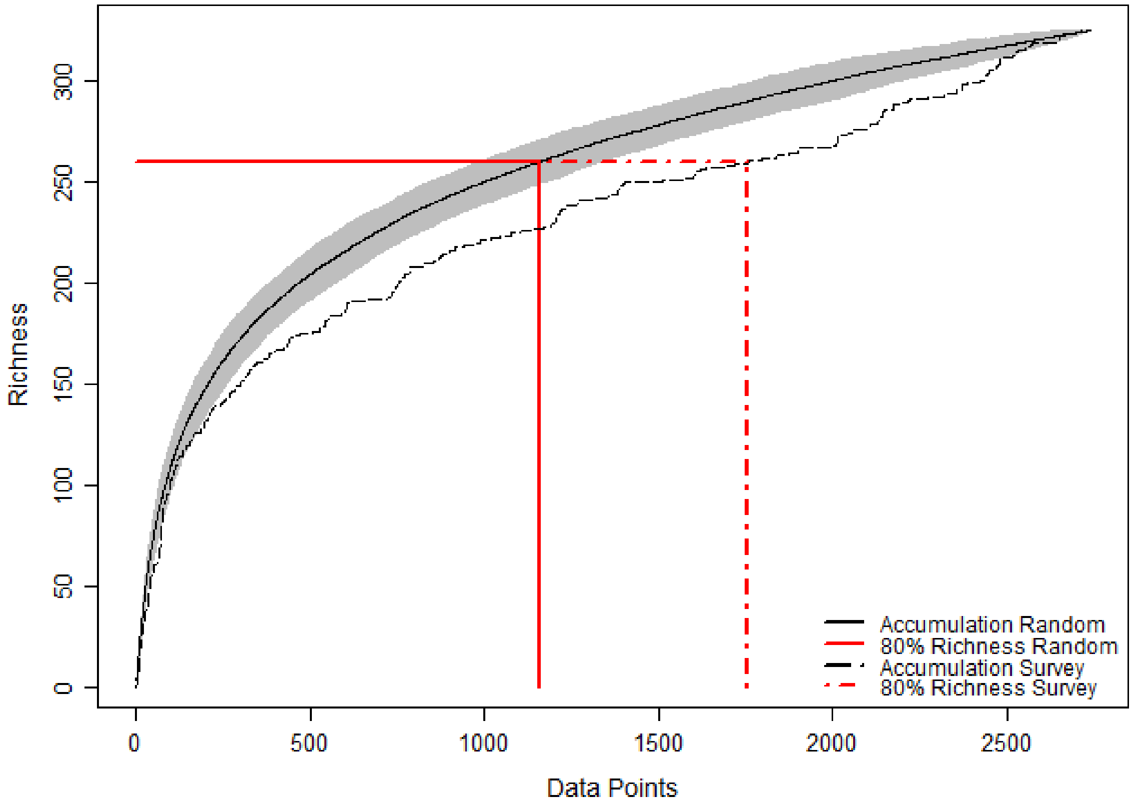


Fig. 1.2. Overlay of two species accumulation curves for the small South African town of Riebeek Kasteel. The solid line curve indicates the random sampling model of species accumulation provided from the data (using specaccum function in R Vegan Package). The surrounding grey polygon indicates the 95% confidence interval. The dotted line curve shows the accumulation of species as data were sampled in our original field-survey where roads were chosen by chance. The data point at which 80 % of the total species for the town is captured is 1178 for the random model and 1756 in the original survey.

We noted, however, that when looking at the species density of sampling points (Supplementary Fig. 1.1), there appeared to be patterns of density on main access roads into the town as well as roads on the urban edge. To test whether this observed pattern would provide a useful strategy for more rapidly accumulating data, we re-ordered the field-survey data according to descending species density per data point and re-ran the species accumulation curve to simulate sampling points in this new sequence. This ‘Density dependant’ approach resulted in only marginally better results (80 % diversity captured after 1479 sampling points) than those of the original survey (1756 points) (Table 1.4).

Since this was not appreciably lower in search effort, we investigated other models to sequentially sample the different road types in the town (post hoc using our original field-survey data). Table 1.3 shows the best results of combinations of road types in contributing to records of alien plant species richness. This shows how parallel roads contained the largest proportion of the town's total species richness for a single road type. If two road types are selected for survey, then the best pair is parallel and perpendicular roads which together account for just over 80 % of the town's alien plant species richness. Sampling these two only would require 50 % of the effort of a full survey. Adding a third level results in the addition of access roads giving the highest richness for any three combinations of roads in this town. By now, the strategic selection of roads has accounted for just under 90 % of the richness for just over 60 % of the effort. Any new additional road types from this point typically only contribute marginal gains (around a 4 % increase in richness for a 10 % additional input of effort), with the last road type, Industrial, only adding 0.3% to the total richness.

Using this sequential combination assessment, the optimal order for strategically surveying the town would have been: parallel roads; perpendicular roads; access roads; low-income; Main road; urban edge road; and industrial roads. When this sampling sequence is plotted on the accumulation curve, the results indicate it would have captured 80 % of the alien plant species diversity in the town a little over 500 data points sooner than our original survey. At 10 m per sampling point, this would have translated to walking just 5 km less – which at our sample speed would only have translated to only around 2 days less than the original survey (less than a 10 % reduction in effort).

Table 1.3: Comparison of results of alien plant species sampling strategies based on road type in the small South African town of Riebeek Kasteel. All public roads were sampled at 10 m intervals in our original survey. Species presence data were then coded according to their location in seven distinct road types: Main road; Parallel to Main road; Perpendicular to Main road; Access roads; Urban edge roads; Industrial area roads; and roads in low-income areas. We defined "low-income areas" as those portions of the town which were the result of racial and economic separation under apartheid legislation before 1994 (see Shackleton and Blair, 2013 and McConnachie and Shackleton, 2010). We then tested all combinations of road types to determine which would result in the largest proportion of the town's total species richness. This was done for all levels of combinations (i.e. choosing one road type; choosing two road types; choosing three road types; etc.). This table displays the best results for each level of road type combination (columns 1 to 6) and indicates the proportion of the town's total species richness obtained by that combination. The proportion of effort is relative to our original survey (which took 2742 data points over 16 person days). We also indicate which roads in what sequence result in the proportion of total species richness for these best combinations shown.

Number of road types sampled	**1**	**2**	**3**	**4**	**5**	**6**
Best Combination of Road Types	Parallel	Parallel; Perpendicular	Parallel; Perpendicular; Access	Parallel; Perpendicular; Access; Low-income	Parallel; Perpendicular; Access; Low-income; Main	Parallel; Perpendicular; Access; Low-income; Main; Urban edge
Proportion of total species richness captured	66.0%	81.0%	89.0%	93.5%	97.5%	99.7%
Percentage of total data points surveyed	29%	50%	61%	71%	83%	97%

Table 1.4: Comparison of several different sampling strategies according to the number of data points each would require to capture 80 % of the total species richness for the small town of Riebeek Kasteel, South Africa. We took total species richness to equal the results from our comprehensive field-survey of Riebeek Kasteel where data points were taken at 10 m intervals along all public roads (see Appendix A.). Results were generated by re-ordering the original field-survey data according to the strategy listed and running a species accumulation curve (using the specaccum function in R Version 3.3.1). Strategies shown are (in order): Our original field-survey data in which roads were sampled in a haphazard manner; Randomised sampling strategy drawn up using the default function in specaccum where data points are sampled at random; Density dependant strategy based on decreasing density of species per sampling point (see Figure 2.); and the Best sequential road-type combination where roads were sorted in decreasing order of each road type's contribution to a cumulative alien plant species count (see Table 1.3).

Sampling Strategy	**Data points required to achieve 80 % of total town species richness**
Field-survey data	1756
Randomised sampling points (specaccum)	1178
Density dependant	1479
Best sequential road type combination (see Table 1.3)	1154

1.3.4 Status

The results of filtering our survey data for evidence of naturalization and spread are shown in Table 1.5 according to their categorisation under the United Framework for Biological Invasions. Since our survey counted all alien plant species, the entire species pool (298 taxa) are at least B1 (transported beyond the limits of their natural range). Forty-five are considered to be naturalized within the town but not yet beyond its borders, while 105 taxa are recorded for Category D1-E (Invasive).

Plotting the abundance of this group of invasive species shows the species which are the most numerous invaders in this town (Fig. 1.3.). Sixty-nine taxa with more than 10 records in the town which were recruiting and spreading without human assistance are recognised as invasive elsewhere.

Table 1.5: Application of the Unified Framework (Blackburn *et al.* 2011) to the survey of alien plant species from the small town of Riebeek Kasteel, Western Cape, South Africa. We indicate the steps at which and degree to which the pool of total species (298) is reduced to reflect landscape-level invaders present in the town. We condensed the Unified Framework into four broader categories and added the initial category of Present, which is the total pool of alien plant species encountered. “Alien but not naturalized” corresponds to categories B1-C1 from the Framework, while “Naturalized but not invasive” corresponds to categories C2-C3. Lastly, “Invasive” corresponds to categories D1-E from the Unified Framework.

Condensed broad categories of introduction status	Number of species recorded in Riebeek Kasteel
Present	298
Introduced but not naturalized	148
Naturalized but not invasive	45
Invasive	105

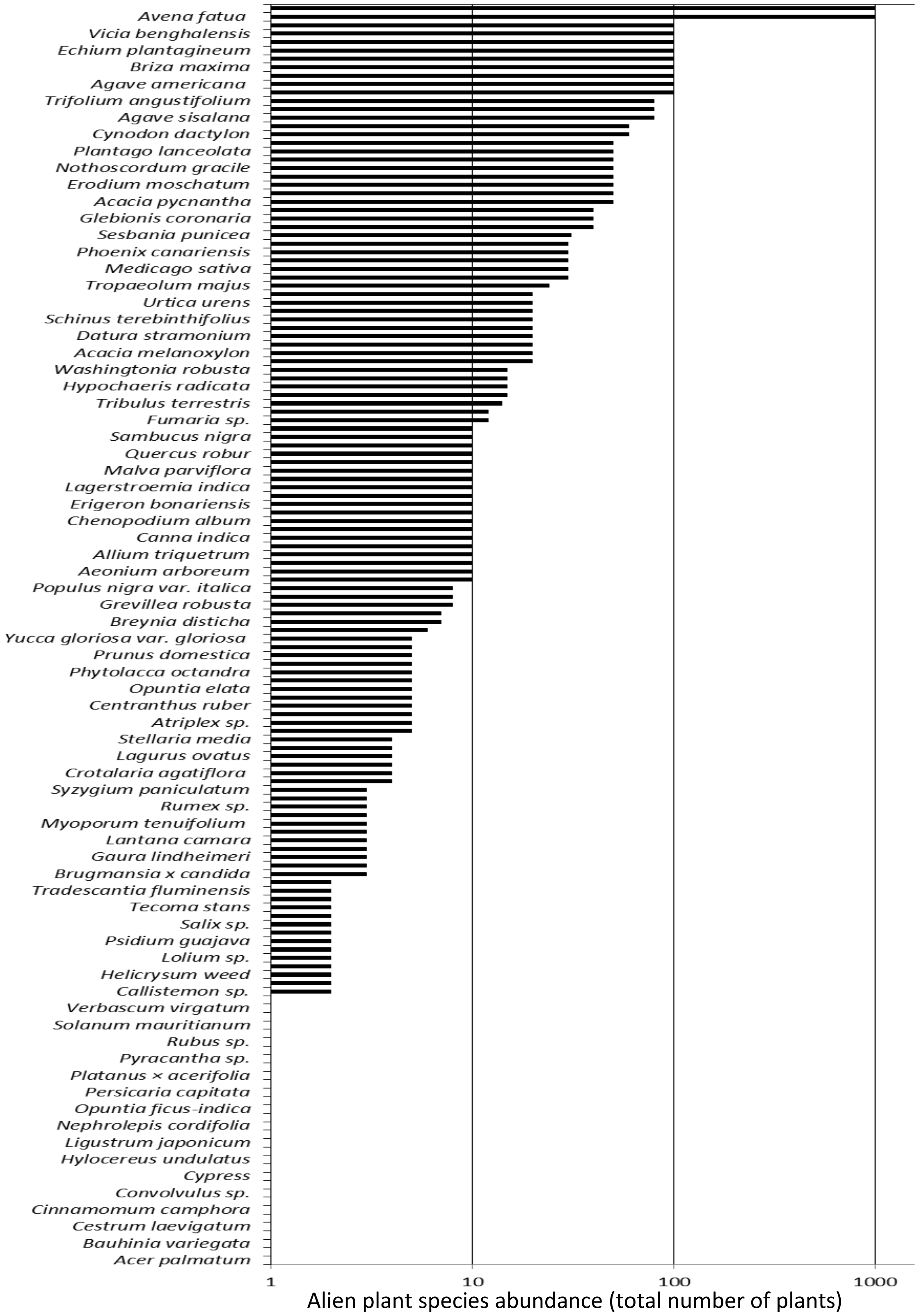


Fig. 1.3. Truncated plot of the abundance of the 105 species recorded as 'Invasive' for the small town of Riebeek Kasteel, Western Cape, South Africa (Category D1-E under the Unified Framework; Blackburn et al. 2011). Abundance is measured as the number of stems for woody species. For spreading or climbing plants, we took every 1m^2 of plant to equal one woody stem equivalent. The y-axis is the log of plant abundance throughout the town.

1.4 Discussion

Our survey provided a detailed assessment of the type and number of alien plants in the small town of Riebeek Kasteel and confirmed our initial hypothesis that there would be differences in the occurrence and abundance of these species across different land-use types. The bulk of this diversity resided in gardens, but each garden was so different from the next, that one needed to sample every garden to ensure a high degree of confidence in the results, which elevated the search effort required. There were no particular broader patterns to the diversity such that it was impossible to strategically survey the town and reduce search effort significantly. Managers should consider the high search effort required (including taxonomic expertise) in their efforts to comply with NEM:BA and should also note that the most abundant species tended to also be invasive.

1.4.1 Distribution

The bulk of species diversity (84 %) resided in the land-use type Gardens (Table 1.1). To capture this diversity, though, one had to survey a large number of data points, meaning that the average number of species encountered at any given point was relatively low for this land-use type. On the other hand, the range of species here was also the broadest, with up to 20 different species being identified at a single data point. This indicates a high diversity within but also between gardens in this town.

Curbs were the next best predictor of diversity which supports other research that shows this land-use type to be a significant pathway for the movement of plant propagules, particularly on the peripheries of urban settlements (Zwaenepoel et al. 2006; von der Lippe and Kowarik 2008; von der Lippe et al. 2013). Another explanation is that this effect is a reflection of the degree to which some homeowners actively plant the curb as an extension of their gardens.

While agricultural areas recorded low overall species richness, these areas had very high abundance of these few species. This result is not surprising, given the typical practice of monoculture farming in the region. Also predictable was the low species richness and low abundance of plants recorded for Industrial land. This land-use type is typically hostile to plants and, in some cases like around electricity supply sub-stations, land is actively treated with herbicides to prevent recruitment of plants. In addition, although Industrial areas contributed 29 % of the total species pool for the town, there were only two species which were found only in this land-use type (*Rumex* sp. and *Persicaria capitata*). This implies that future urban-specific surveys need not pay undue attention to this land-use type if time efficiency is an important factor.

When considering the most abundantly occurring plants within each land-use type, it was evident how many are listed as invasive under national legislation or in the literature as problem plants in the region (Table 1.2). Industrial areas and Urban Green Spaces had only one and two plants respectively within the top 20 most abundant species that were not problematic plants or listed invasives. Problematic plants or listed invasive species account for the majority (78 %) of the most abundant plants for all land-use areas.

1.4.2 Sampling effort and strategy

The intensive survey resulted in a comprehensive assessment of the alien flora of Riebeek Kasteel. The high number of invasive plant species recorded in the total alien species pool

(33 %) is in line with findings from large cities in other parts of the world; e.g. Tait et al. (2005) for Adelaide and 32 % for Berlin (Kowarik et al. 2013). This is interesting because large cities are predicted to have a greater number of alien plant species (due to the greater number of pathways they have for ingress; e.g. ports, airports, railway hubs), yet our data suggest that the proportion of invasive species is similar in smaller towns.

The field-survey method was time-consuming and required a high level of expertise to identify the suite of alien plants encountered. This level of search effort makes it unlikely that this particular comprehensive-survey methodology will be useful or cost effective in large-scale attempts to produce alien plant inventories in other small towns. When we plot the species accumulation curve according to the way it was collected in this survey (streets and directions chosen by chance) (Fig. 1.2.) it is clear that there is no appreciable levelling off of the curve over time. This lack of saturation indicates that alien plant species diversity is high across the town such that we encountered novel species fairly regularly until completion of the survey, which explains why such a high degree of search effort was required.

However, it is possible that this is a reflection of the lack of underlying 'search strategy' in the survey methodology. For example, we noted how certain areas like the main roads into the town and urban edge roads had the greatest number of species per data point (Supplementary Fig. 1.1). For this reason we attempted to stratify the survey results by road sampled, using the more species-dense locations of main access routes into the town and urban edge roads before sampling other roads within the town. Interestingly, this sampling strategy was only marginally better than the haphazard sampling strategy used in the original survey (Table 1.4). We conclude that this effect was due to the lack of diversity between each data point on these roads. Many of the species located at these points were agricultural-origin problem species like *Avena fatua* and *Echium plantagineum* which were spreading towards the town along disturbed roadsides. Although each data point might contain more than 15 species, the predominance of these problematic plant species meant that the following point would contain the same species component and thus add nothing new to the novel species accumulation curve. Thus, the density of species sampled at any point is not indicative of the diversity over the whole town.

To determine a better strategy, we tested models of species accumulation based on the sequential addition of different road types. What was apparent, however, was that, in order to gain sufficiently high species richness figures, search effort remained very high. Spatial autocorrelation within the town prevented any strategy from performing meaningfully better than the simulation's randomised sampling strategy; meaning the best saving in effort we could generate using this post hoc approach was less than 10 % of the effort of our full survey.

Interestingly, despite some minor changes to the rates at which species were recorded, none of the curves we ran indicated any degree of saturation, suggesting that no matter how the town was sampled, novel species would continue to be recorded as the search area increased. Even the default curve where sites are sampled at random (Fig. 1.2.) showed no levelling off and all strategic sampling methods attempted resulted in only marginal in reductions search effort. These results echo those obtained in a larger town in South Africa (Tlokwe City) by Lubbe et al. (2011) as well as those from a study in the UK (Smith et al. 2006). This reflects the very high species diversity typical of gardens and garden plantings in urban environments, which is also supported by our results of species richness by land-use type in this town. Each garden effectively represents a clean slate for the landowner to plant whatever species they desire or can locate (or that they can keep alive, if the local environmental and climatic conditions differ extensively from those in the species' natural range). There is thus no necessity for any two gardens to have similarity in their species composition and, as pointed out by Smith et al. (2006), the available pool of alien plant species in any garden is a function of the range of species available through the horticultural trade which is a major pathway for plant invasions worldwide (Richardson et al. 2003; Dehnen-Schmutz et al. 2007a,b; Foxcroft et al. 2008; Lambdon et al. 2008). This explains much of the diversity in alien floras of cities (Sanz-Elorza et al. 2008; Marco et al. 2010; Asmus and Rapson 2014). The availability of additional species through the global internet trade in recent years only enhances this effect (Lenda et al. 2014). This site/garden-specific diversity means that in an urban plant survey, one finds novel species fairly consistently until the entire area is surveyed. This finding is important for other studies involving species estimates from partial urban surveys, as these will need to consider the number of gardens not sampled in order to extrapolate more accurately.

1.4.3 Status

Our data show that half of the alien plant species recorded for this small town are at least naturalized within this urban space. While nearly a third of the total species pool shows evidence of invasion in the region, the 46 naturalized but not invasive species should be subjected to risk analysis to determine whether they contribute to invasion debt (as contemplated by Rouget et al. 2016).

1.5 Conclusions

The alien plant flora of this town comprised mostly problematic plants and listed invasive species which may have important implications for the surrounding area which is subjected to increased propagule pressure from these problem plants. The most abundant species are those most likely to be at least naturalized but potentially invasive, so management attention should focus on these. These results imply that small towns have the potential to be major contributors of propagules which may launch new invasions (or support existing ones) in the areas that surround them.

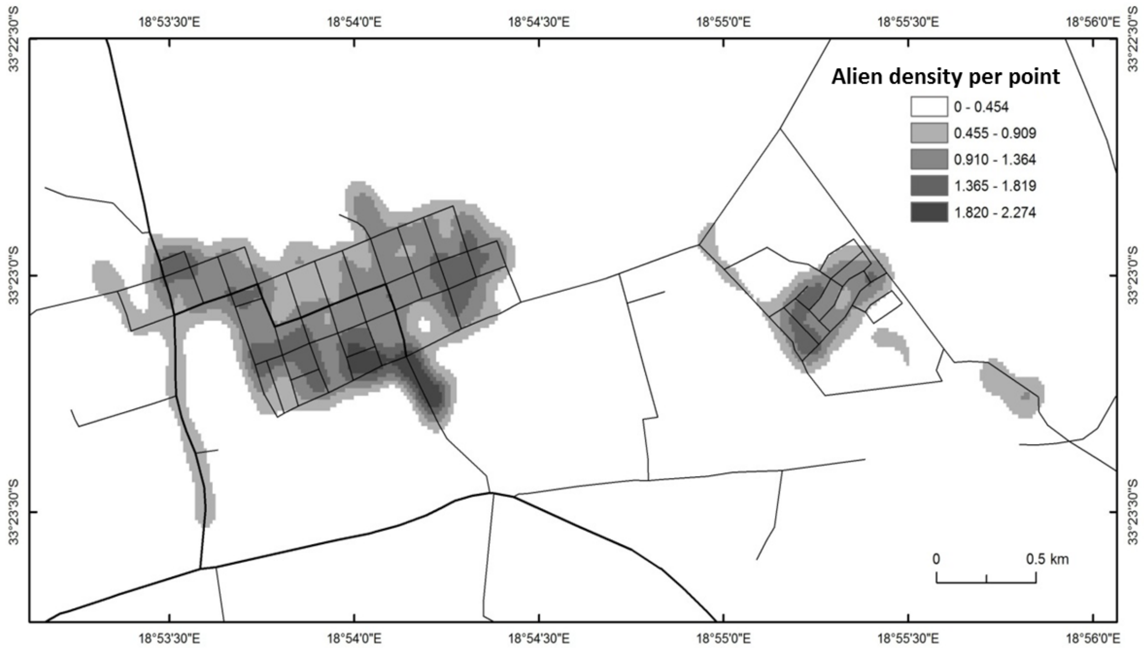
Indications on the type and status of alien plants within urban areas is an important consideration for municipalities under NEM:BA, but due mainly to context dependence and the heterogeneity between gardens, our results indicate that accurate assessments require a high level of taxonomic knowledge and a large investment in search effort.

Acknowledgements

We acknowledge funding from the DST-NRF Centre of Excellence for Invasion Biology and the National Research Foundation (grant 85417 to DMR). Additional support was provided by the South African National Department of Environmental Affairs through its funding of the South African National Biodiversity Institute Invasive Species Programme (SANBI). We thank Pieter Winter and Adam Harrower for help with plant identifications, and Philip Ivey, Reshnee Lala and Haylee Kaplan for reviewing previous drafts of the manuscript.

Supplementary Table 1.1: Data sheet used to capture a range of information for each waypoint marked in the field.

DATE:			TOWN:					Recruiting?		
Waypoint	**Obs Zone**	**Species**	**Number of individuals**	**Square metre cover**	**Growth Stage**	**Planted Y/N**	**Land use Type**	**Could it recruit?**	**Has it recruited?**	**Notes:**



Supplementary Fig. 1.1. Location of all waypoints sampled in Riebeek Kasteel where roads were treated as transects and alien plant species were recorded at 10 m intervals. The diagram indicates the number of different species encountered at each sampling point using the Kernel Density tool in Spatial Analyst ArcMap 10.4 (ESRI 2015). Readings are then smoothed between points (data points were not shown as they made the map difficult to read). Our survey did not record data more than 15 m distant from each data point. Therefore the white background evident in this map indicates both low species density per data point and also those areas not sampled.

Chapter 2:

Challenges in compiling inventories of invasive alien plants in small towns:

Insights from South Africa's Berg River catchment

This chapter is intended for submission to the journal *ABC Bothalia*

Authors: Phil McLean[1,2], John R.U. Wilson[1,2], Laure Gallien[1], Mirijam Gaertner[1,3] and David M. Richardson [1]

Address: [1] Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.
[2]South African National Biodiversity Institute, Kirstenbosch National Botanical Gardens, Private Bag X7, Claremont 7735, South Africa.
[3] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

Contribution of each author:
PM, DMR, JRUW & MG: Planning and design of the study.
PM: Conducted fieldwork, species identification, statistical analyses and led the writing.
DMR: Commented on the manuscript and improved the writing.
JRUW: Commented on the manuscript and provided statistical advice.
MG: Provided comments on the manuscript.
LG: Commented on the manuscript and provided statistical advice.

Abstract:

Cities are large urban areas and are hotspots for plant invasions, yet small urban areas are more numerous in the landscape and have larger edge to area ratios, meaning they can successfully launch invasions into surrounding areas. South Africa has developed national legislation to manage invasive species in which landowners (including municipalities with their associated urban components) have a 'duty of care' to compile inventories, report and control listed invasives. The vast majority (97 %) of municipalities in South Africa are under-resourced relative to metropolitan areas but contain many small towns, all of which can contribute to invasions in surrounding land. Due to their limited resources and expertise most under-resourced municipalities struggle to comply with national legislation and fail to list and manage major invasive plant species; including those within their urban component.

Our aim was to explore patterns in the location and distribution of both alien and invasive plant species within and between small towns that could help guide future surveys of alien plants in urban areas, thereby assisting municipalities to comply with national legislation.

We applied a road-based, urban-specific survey of alien plants along selected roads in 11 small towns in the Berg River catchment. The invasive species subset of this total pool was determined using overlaps in records between our surveys and a database of naturalized plants (the Southern African Plant Invader Atlas). Collected data were used to determine whether population density, road network length or the age of a town could predict the numbers of alien and invasive plant species found there. We also used the data to explore patterns of richness of alien and invasive plant species according to land-use type, and road type within towns.

In the surveyed towns, only total road length predicted the number of alien plant species in towns. The highest alien plant species diversity resides in gardens and roadsides near the town centre and in adjacent low-income areas. Similar patterns exist for invasive plant species. High heterogeneity between gardens within towns contrasts to general homogeneity of urban alien flora for the region.

Urban alien plant richness is driven mainly by diversity within gardens, indicating that garden surveys will capture the majority of a town's alien plant species. However, turnover between gardens and context specificity means that selecting any subset of gardens risks missing key data. Nonetheless, one can estimate which plants within the urban space are most likely to invade the surrounding areas by surveying low-income areas and town centres, and comparing these species to databases of naturalized species for the region. Such insights will be useful for designing protocols for the rapid sampling of alien floras in small towns.

2.1 Introduction:

Plant species that are moved by humans to new biogeographic regions and then become invasive in their new habitat are a major environmental problem in many parts of the world (Pyšek and Richardson 2008; Vilà et al., 2011; Pyšek et al. 2012), including South Africa (Richardson et al. 2011b). Many pathways exist for their movement around the globe (e.g., Faulkner et al. 2015). Because of their many ports of entry and/or trade, cities are often the point of introduction for many alien species (Pyšek 1998; Vitousek et al. 1997a,b; Dodd et al. 2016; Padayachee et al. 2017). Amongst the many pathways, ornamental horticulture is a major vector for the introduction of plants into new regions and for the dissemination of these species within the new regions (Reichard and White 2001; Sanz-Elorza et al. 2008; Marco et al. 2010; Asmus and Rapson 2014).

Most studies on alien plant invasions in urban areas have focussed on large cities (e.g. Alston and Richardson 2006; Lambdon et al. 2008; Botham et al. 2009; Aronson et al. 2014b; Garcillán 2014; Lenda et al. 2014). Among the issues that have been addressed is the spread of alien plants from urban areas into the surrounding natural and semi-natural areas (Alston and Richardson 2006; Botham et al. 2009; Marco et al. 2010; Mclean et al. 2017). Such spread may be achieved by “jumping the garden fence” by exploiting opportunities to recruit in the often highly disturbed areas surrounding urban areas (Alston and Richardson 2006; Buckley et al. 2007; Cilliers et al. 2008), or by human-facilitated dispersal directly into surrounding areas, often through the movement of vehicles (Zwaenepoel et al. 2006; von der Lippe and Kowarik 2008; von der Lippe et al. 2013).

Despite the bias towards large cities in the literature on urban plant invasions, authors like Marco et al. (2008) caution that there is a higher probability of alien plants colonising neighbouring habitat from small urban areas, particularly urbanising rural areas, or towns. This is due to the higher edge: area ratios (relatively long interfaces between urban gardens and the uncultivated habitats outside urban areas) in smaller urban areas.

In many parts of the world small towns, which greatly outnumber cities, are embedded in the landscape as they arise from the urbanisation of rural areas (Marco et al. 2008; McLean et al. 2017). Alien plants thus have many opportunities to spread across the landscape from small towns. Indeed, observations have found that those plants which are planted close to the edge of the urban expanse (Moreira-Arce et al. 2014) and the edges of suburban gardens in particular (Marco et al. 2010), have an increased probability of escaping into the surrounding areas.

The prevalence of alien over native species in ornamental gardens in many parts of the world increases the potential for the establishment of new invaders (Reichard and White 2001; Lubbe et al. 2011; Ööpik et al. 2013; Cubino et al. 2015). There are thus high levels of invasion debt (*sensu* Rouget et al. 2016): even if no new species are introduced, many that are already planted will become invasive in the future (Downey and Glanznig 2006; Asmus and Rapson 2014; Cubino et al. 2015). This means that small urban areas (hereafter "towns") need to be studied to understand the patterns and distributions of alien plant species within them and their potential to serve as launching sites for invasions in surrounding environments in the future.

South Africa has enacted national legislation which stipulates that all landowners (and organs of state, including municipalities) are responsible for a 'duty of care' with respect to managing invasive species on land under their control: *The National Environmental Management: Biodiversity Act* (Act 10 of 2004; hereafter "NEM:BA"; DEA 2014). Such management must take the form of a plan, the first facet of which involves a detailed inventory of listed invasives in the area. However, a recent study by Irlich et al. (2017) found that most municipalities in the country were delinquent in their responsibilities under NEM:BA. Only two out of the 8 large ("metropolitan") municipalities had achieved some level of compliance, while almost none of the 249 less well-resourced or "rural municipalities" reported any progress towards compliance with NEM:BA. Among the barriers to compliance were that less well-resourced municipalities lacked the capacity to undertake the necessary research and surveys. An important barrier is that available regional maps and databases of invasive species distribution are inadequate for compiling inventories at the scale of municipal management plans (Koma 2010; Ruwanza and Shackleton 2016). Given the scope of the task in the context of the lack of capacity and progress to date, a huge knowledge gap needs to be filled.

Municipalities in South Africa are defined by geopolitical boundaries which contain of a matrix of urban, agricultural and natural and/or semi-natural areas. So to properly formulate their plans under NEM:BA, municipal managers must also consider the urban aspect of their landscape. There is thus a need to develop an urban-specific methodology to assist managers and consultants in fulfilling the requirements for NEM:BA compliance to develop invasive plant species inventories for urban areas.

Such urban plant surveys are generally difficult to undertake due to a variety of challenges, including the limitation of mobility over, and access to, private land, high time investments and the requirement for skilled researchers (Pyšek 1998, Marco et al. 2008; Lubbe et al. 2011; Cilliers et al. 2012). While most urban plant surveys have been conducted in large cities (Lambdon et al. 2008; Botham et al. 2009; Aronson et al. 2014b; Garcillán 2014; Lenda et al. 2014), the survey-design challenges they faced are similar to those in small towns; chiefly, that one must prioritise what to survey. For example, Marco et al. (2008) used road and garden surveys across different housing densities in France, while Lubbe et al. (2011) selected random cells from a grid overlay in urban areas in the Tlokwe municipality, South Africa. The former approach gave a high level of detail over a relatively small scale, whereas the latter provided a more general overview over a much larger scale.

There is a need for a method to provide a rapid overview of the alien flora of a given town, but which is accurate enough to gather species data that would be useful to municipal managers. Our aim therefore, was to apply an urban-specific alien plant survey methodology to a selection of small towns within a designated area independent of municipal boundaries, and use the results to determine where in these towns one would find the highest proportion of alien plant species for the lowest search effort (are there ‘hotspots’ of alien plants within towns).

2.2 Methods

2.2.1 Study area

The Berg River Catchment in the Western Cape Province of South Africa (Fig. 2.1.), was selected as the study area. The catchment includes small towns from five different local municipalities, namely: Drakenstein, Stellenbosch, Swartland, Berg River, and Witzenberg. It is bounded by the Jonkershoek and Hottentot's Holland mountains in the south and east and the Atlantic Ocean in the northwest. The predominantly winter rainfall varies from less than 300 mm yr^{-1} along the coast to 3200 mm yr^{-1} in the mountainous south.

The area supports dryland agriculture (mainly wheat) in the northern and western sectors, and irrigated soft fruit orchards in the wetter south and adjacent to the mountain ranges. Natural areas comprise mostly fynbos shrublands with high species diversity and levels of endemism, of which four hundred and fifty seven native plant species are listed as threatened in this catchment, including two hundred and seventy that are either Endangered or Critically Endangered (South African National Biodiversity Institute 2006).The Berg River is 294 km long and riparian habitats along its banks are dominated by alien trees and shrubs (Tererai et al. 2013).

This catchment is a major water source for the urban and agricultural concerns in the area, most notably the city of Cape Town which lies c. 70 km to the southwest, just outside the catchment. For this reason there is substantial interest in environmental issues in the area, including the management of invasive species; the alien flora of the catchment has therefore been relatively well studied (Ruwanza et al. 2013; Tererai et al. 2013; Fill et al. 2017; McLean et al. 2017).

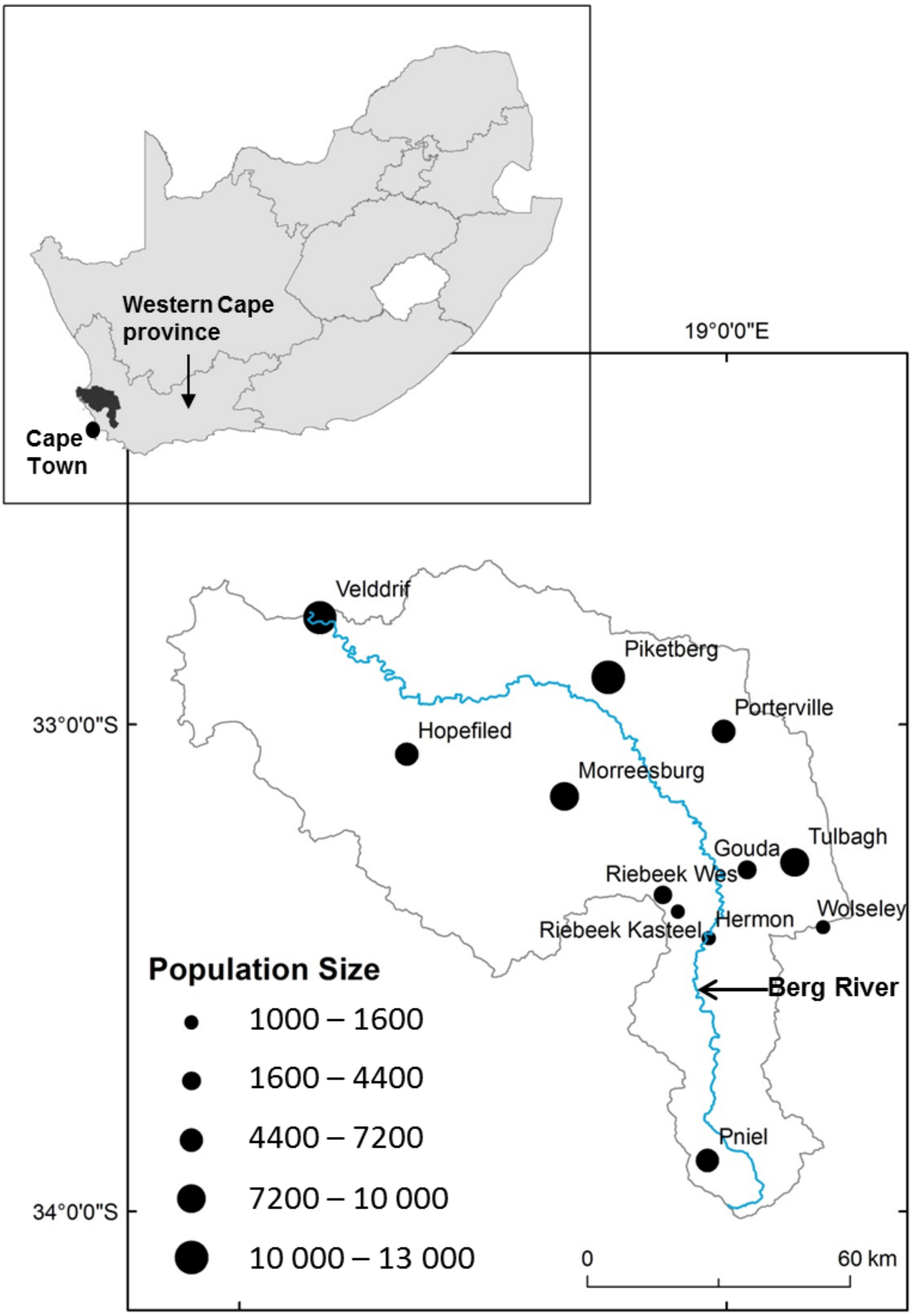


Fig. 2.1. Location of the Berg River catchment (is 7715 km^2 in extent) in South Africa's Western Cape Province. Surveyed towns are indicated by dots with sizes that are proportional to human population sizes. The Berg River is indicated with the arrow. Details of the towns appear in Table 2.1 and Supplementary Table 3.1

There are 28 urban areas within the catchment (Supplementary Table 3.1); these range in population size from 330 to just over 100,000 with population densities ranging from 10 to 5,000 people/km2. So for the purposes of this study we used a population-dependant settlement hierarchy (Doxiadis 1968) and defined 'small towns' as those containing between 1,000 and 15,000 inhabitants (as defined by census information from 2011 available from Statistics South Africa). This gave us a set of eleven towns that varied in population size, density, number of households and household size distributed throughout the catchment, from coastal (Velddrif) to mountainous areas (Pniel) (Fig. 2.1; Table 2.1).

Table 2.1: All small towns located in the Berg River Catchment, South Africa, surveyed for alien plants using an urban-specific, public-road-based inventory. Population density is according to StatsSA census information from 2011. No population data were available for the small hamlet of Hermon due to its inclusion in a neighbouring region. The dates of establishment for Gouda and Hermon are unknown.

Town	Population Density (people/km^2)	Date of establishment (year)	Total road network length (km)	Total number of alien species	Number and proportion of naturalized species
Gouda *	450	?	52	88	37 (42.0%)
Hermon *	nd	?	4	78	36 (46.2%)
Hopefield *	199	1844	90	85	34 (40.0%)
Morreesburg *	285	1882	203	110	42 (38.2%)
Piketberg *	910	1840	76	102	40 (39.2%)
Pniel *	5 046	1843	77	100	41 (41.0%)
Porterville *	884	1863	122	106	43 (40.6%)
Riebeek Wes *	1 269	1858	65	106	43 (40.6%)
Tulbagh *	2 353	1795	75	106	43 (40.6%)
Velddrif *	1 242	1946	111	91	33 (36.3%)
Wolseley *	650	1875	103	100	36 (36.0%)

2.2.2 Surveys:

With the aim of contributing towards the development of an efficient urban alien plant survey methodology, we considered the challenges faced by municipalities in compiling inventories of their urban flora (Irlich et al. 2017). In the previous chapter, we found that the greatest diversity of alien plant species in small towns in the Berg River catchment resided in gardens and roadsides/curbs in the town centre and the adjacent low-income parts of town. Using this as a guide, we drew further inspiration from the Marco et al. (2008, 2010) public-road-based survey (but we did not attempt direct individual garden access as they had done) and incorporated an adaptation of the moving-vehicle method employed by Milton and Dean (1998) to cover greater distances in shorter periods of time.

For each town, we studied maps in Google Earth (Google Earth, 2012) and divided all public roads into six road types (see previous chapter) and surveyed one of each road type per town chosen randomly. These road types were: Access roads (main points of vehicular entry into towns often linking the town's main road to a major highway in the region); Main roads (the main commercial road running through the town); Urban edge roads (those roads on which only a single row of residential plots were immediately adjacent to undeveloped areas, in some cases agricultural, in others natural and semi-natural areas); Parallel roads (roads running parallel to the town's Main road); Perpendicular roads (roads which were perpendicular to the town's main road); Low-income area roads (roads in so-called low-income or segregated township areas). We defined these "low-income areas" as those portions of the town which were the result of racial and economic separation under the previous apartheid legislation (see Shackleton and Blair, 2013 and McConnachie and Shackleton, 2010).

Public roads were thus treated as transects along which data on the type and number of all alien plants were collected. All surveys were conducted by the same researcher, occasionally with the assistance of a field assistant. Besides identifying species and recording occurrence, we also noted the land-use pertaining to the location of each record according to the following classes (after McLean et al. 2017) with the addition of low-income areas as a separate land-use class: Agricultural land; Garden; Roadside/Curb (whether bordering garden or agricultural land); Urban Green Space (we used an adaptation of the definition used by Cilliers et al. (2012) which includes publically accessible spaces in the town, whether formally gardened or not including parks, churches and open plots); Industrial (including commercial space and the waste water treatment works); and Low-income areas (as defined above). Due to the very low representation of species, we specifically ignored 'Industrial roads' as defined by McLean et al. (2017), although we did note this land-use type when it was encountered on other roads (for example, electrical sub-stations positioned on a town's Main road).

Road lengths were measured to correct for search effort in subsequent analyses. Since road-types in low-income areas were typically indistinct (e.g., no obvious Main road and therefore no clearly defined Parallel or Perpendicular roads either), we surveyed these areas by averaging road lengths sampled for all other roads in a given town, and surveying a similar distance along randomly chosen roads in the low-income region.

When field identification was not immediately possible, photographs and, when appropriate and possible, physical samples were taken for referral to taxonomists or horticulturists for identification. Nevertheless, some taxa require very close proximity for accurate identification to species level (for example *Eucalyptus*, *Callistemon* and *Pinus* species). Since this was not universally possible, we identified all taxa in such "problem genera" to genus level only to avoid any representational bias.

2.2.3 Database of naturalized and invasive plants:

We needed to establish which subset of the alien plant species recorded in our field-surveys was less reliant on the altered conditions within urban cultivation and thus able to colonise and spread into the surrounding environments.

We therefore compiled a database of all naturalized and invasive plant species in the catchment listed in the Southern African Plant Invader Atlas database (SAPIA; accessed 9 June 2016). SAPIA is a repository of records of naturalized and invasive plants outside of captivity or cultivation throughout Southern Africa (Henderson and Wilson 2017). This means, any plant species recorded in the SAPIA database for this region as well as in our town surveys, are clearly less reliant on the modified conditions that exist in towns and are able to spread into the surrounding areas. Of course, some of these species will be those which are spreading into urban areas (for example *Echium plantagineum*, an agricultural-origin invader). But these species too are important in the context of spreading alien plants and thus NEM:BA legislation, so their existence and location in urban areas is still relevant.

Criteria used to categorize species as alien, naturalized and invasive in this study are those elaborated by Blackburn et al. (2011) and Richardson et al. (2011a). We thus categorize a species as 'alien' if its presence in the study area is clearly attributable to human-mediated introduction across a major biogeographical barrier. 'Naturalized' species are those alien species which reproduce and have established self-sustaining populations in the study area, while 'invasive' species are naturalized species that have spread over substantial distances from sites of introduction/planting in the study area.

2.2.4 Analyses:

2.2.4.1 Determinants of alien plant species diversity:

In order to examine differences in the numbers of alien plant species found between small towns in our study area, we compiled a database of information for towns surveyed which included each town's date of establishment and population density which we obtained from Statistics South Africa's 2011 Census data (StatsSA 2016) (see Table 2.1). To this database we added each town's total road network length which we established using road data at a scale of 1:50 000 in ArcGIS 10.4 (ESRI 2015).

We then treated each town as a separate plot and ran generalised linear models to determine the significance of any relationships between the range of town-specific descriptors (town age, town population density, and town total road network length) and their ability to predict the response variable of the number of alien plant species recorded per the town in our survey. This analysis was run using the glm function in R 3.3.1 (R Core Team 2013). We repeated this test for the subset of the total species encountered which exhibit signs of independence from the potentially altered growing conditions found in towns (i.e. those listed in SAPIA – see above).

To determine whether the numbers of recorded alien plant species significantly differed across land-use types, we ran two-way Tukey t-tests (testing all pairwise combinations of land-use types) with the glht function in the multicomp package in R 3.3.1 (Hothorn et al. 2008). We also tested whether invasive plant species revealed distribution patterns based on land-use types, so we repeated the analysis for those species recorded in the SAPIA database.

To determine the relationships between the survey road types and the number of alien plant species encountered there, we repeated the two-way t-tests described above after first factoring in the length of roads to account for search effort. Since we were also interested in the invasive species distribution by road type, we ran the two-way Tukey t-tests as before using those plants found in our towns surveys but which were also recorded within the SAPIA database.

To determine any broad patterns in the regional turnover of alien plant species between towns, we ran a nestedness analysis following the approach elucidated by Foxcroft et al. (2008), and using the nestedtemp and oecosimu functions in the Vegan package in R 3.3.1 (Oksanen et al. 2013). Nestedness temperature is a measure of the degree of similarity between a set of sites and ranges from 0 (completely identical) to 100 (zero similarity between sites).

2.3 Results

2.3.1 Determinants of alien plant species diversity across towns:

The total length of all roads in towns was a good predictor of the total number of alien plant species observed in them (z-value=5.929; $P<0.001$) (Supplementary Table 2.1), while human population density was only a very weak (not significant) predictor of the number of alien plant species observed (z-value=1.884; $P=0.060$) (Supplementary Table 2.1).

The results of the same analysis conducted using those species listed in the regional naturalization database of SAPIA revealed similar results with regards to total road network length (z-value=2.211; $P=0.027$) (data not shown), but no other variables were significant.

2.3.2 All alien plant species distribution in towns:

The number of alien plant species occurring on the different land-use types was significantly different in towns with Gardens and Low-income areas reporting significantly higher proportions than other land-use types. Low-income areas were also significantly more speciose than gardens. Agricultural, Industrial and Urban Green Space areas were not significantly differentiated from each other (Fig. 2.2 a).

When looking at alien plant species distribution according to road types across all towns (corrected for the length of the roads surveyed for each road type), results indicate that low-income roads have the highest number of species but that these are not significantly higher than the results for roads in town centres (main, perpendicular and parallel roads). Access roads and urban edge roads have the poorest diversity of alien plant species of the road types assessed (Fig. 2.3a).

2.3.3 Invasive plant species distribution in towns:

These are the results of the same analyses as performed above, but run only for the set of invasive plants found in towns but also found in the SAPIA database for this region.

The results are similar to those for all alien plant species with low-income areas recording significantly higher numbers of invasive species than the other land-use types. Next highest was gardens, but the remaining land-use types were not significantly different from each other (Fig. 2.2 b).

Significantly more invasive plant species were recorded for roads in low-income areas than all other road types ($P<0.001$) (Fig. 2.4.). When this result is corrected for the length of survey roads (i.e. search effort), low-income area still contained the greatest number of species, but not significantly more than Perpendicular ($P= 0.671$) and Parallel roads ($P= 0.506$) (Fig. 2.3b).

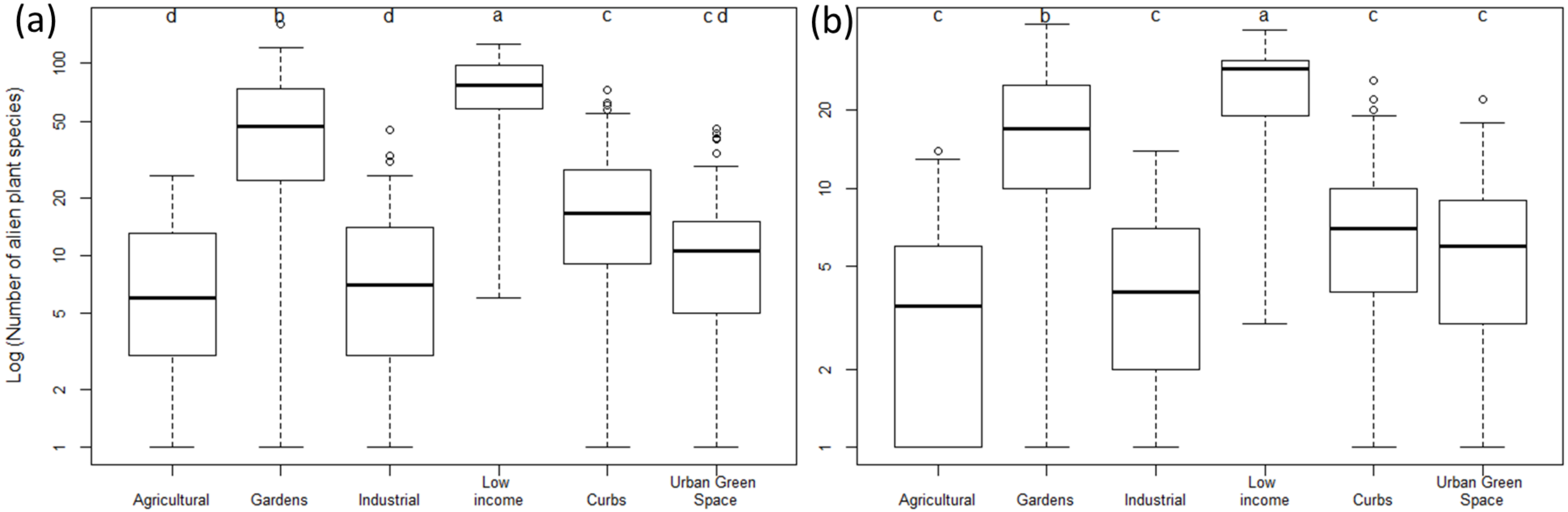


Fig. 2.2. Alien plant species richness per town across six land-use types in 11 small towns in the Berg River catchment, South Africa. Panel **(a)** is the total number of alien plant species for each land-use type, while **(b)** shows the number of invasive plant species recorded for each land-use type. Invasive species are the subset of species from our surveys of towns that are also known to be naturalized (and are listed in the Southern African Plant Invader Atlas). The y-axis is logged as data were not normally distributed. Boxes indicate 50 % of the total data while the thick middle line is the median number of species for that land-use type. Whiskers show the upper and lower quartiles of the data and dots show outliers. Different letters indicate land-use types that differed significantly at $P<0.05$.

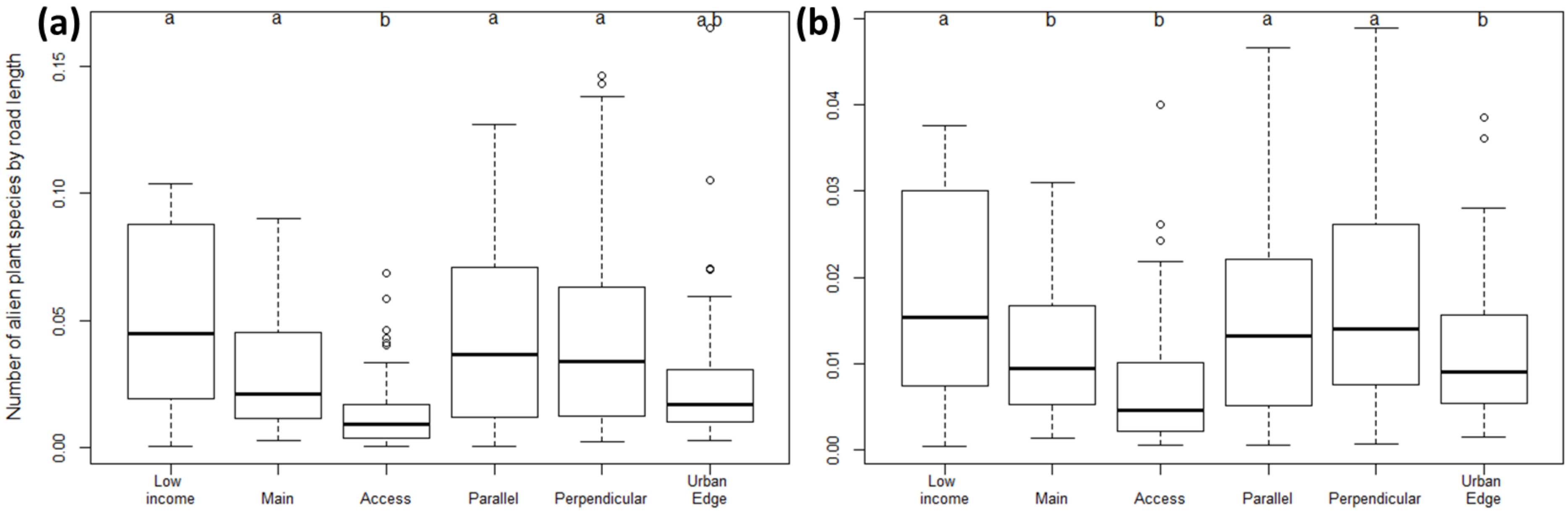


Fig. 2.3. Alien plant species richness according to six road types used to survey 11 small towns in the Berg River catchment, South Africa. Panel **(a)** shows the numbers of all alien plant species recorded during our urban-specific survey for each road type where these numbers were corrected for road length (so that they represent equal search effort). Panel **(b)** shows the numbers of invasive plant species within each surveyed road type, also corrected for road length surveyed to account for search effort. Invasive species are the subset of species from our surveys of towns that are also known to be naturalized (and are listed in the Southern African Plant Invader Atlas).

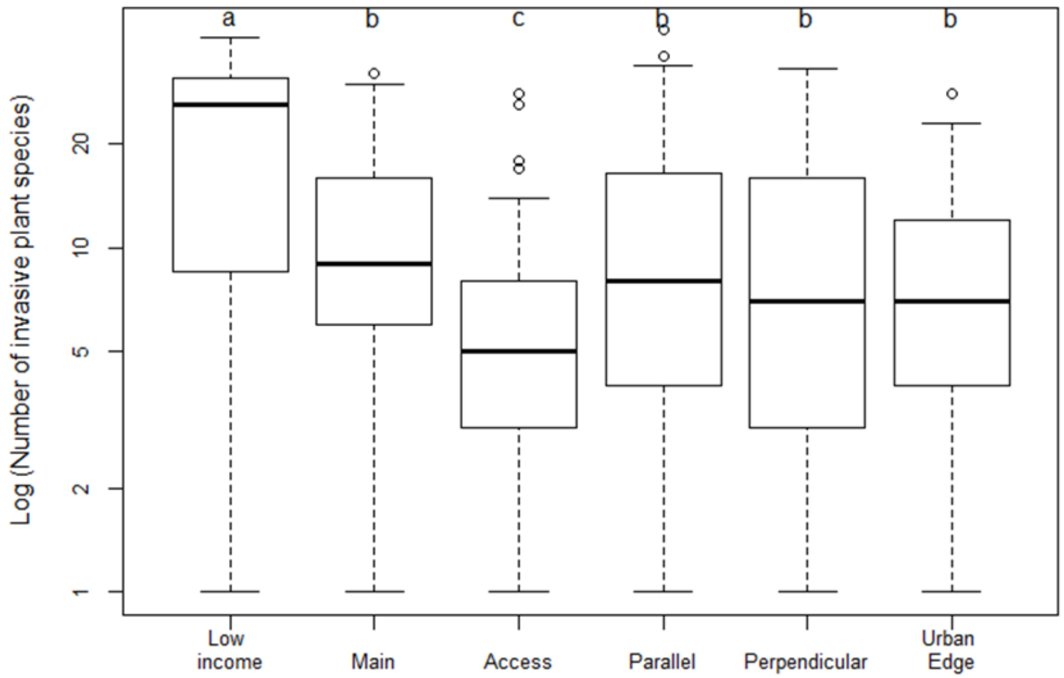


Fig. 2.4. Invasive alien plant species richness according to six road types used to survey 11 small towns in the Berg River catchment, South Africa. This panel shows the numbers of alien plant species for each road type when road length is not factored in (logged y-axis). Boxes indicate 50 % of the total data while the thick middle line is the median number of species for that land-use type. Whiskers indicated by the dotted lines show the upper and lower quartile of the data and dots show outliers. Different letters indicate land-use types that differed significantly at $P<0.05$.

2.3.4 Alien plant species richness between towns:

For this study we calculated a nestedness temperature of 24, indicating a very high degree of similarity between all towns (very few species only recorded in a single town) (Fig. 2.5.).

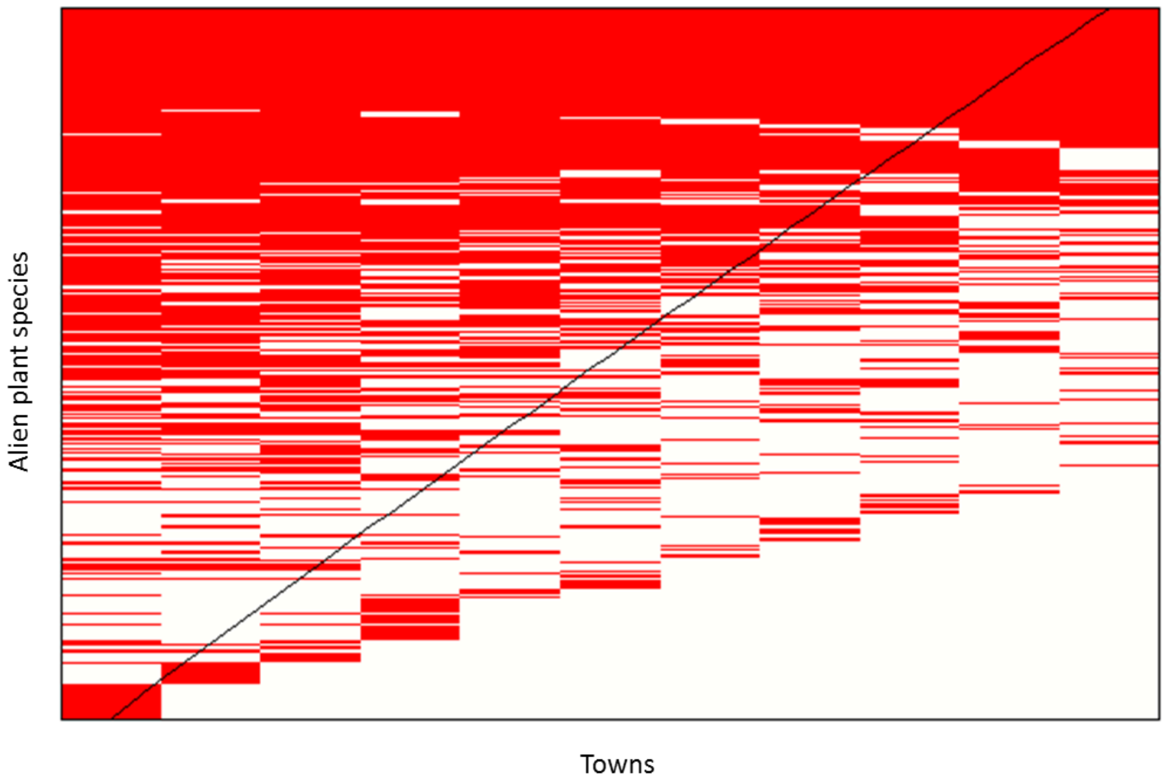


Fig. 2.5. Maximally nested matrix of alien plant species recorded in surveys across 11 small towns in the Berg River catchment, South Africa (compiled using the nestedtemp function in the Vegan package in R Version 3.3.1; Oksanen et al. 2013). The nestedness temperature for this dataset is 24 on a scale of 0 (perfectly nested) to 100 (perfectly random). This indicates a very high degree of similarity (or homogeneity) across towns in the region (data checked for non-randomness using oecosimu function in R against 99 null-model simulations: Checkerboard Units: 99514; C-score: 1809.34; P<0.01).

Discussion:

Our results indicate that the population density of small towns does not explain the number of alien or invasive plant species found in them. This is contrary to results from research in larger cities (Aronson et al. 2014a,b) and protected areas (Spear et al. 2013), but may be a function of the small sample size investigated here. Town age was similarly unrelated to the number of alien or invasive species recorded. Previous work in the same catchment also found no correlations between a given town's ability to host alien and invasive plant species and several environmental gradients (mean annual temperature and mean annual rainfall) nor a human footprint index (Mclean et al. 2017). It therefore appears that small towns in this region are equally capable of hosting a suite of alien plant species, irrespective of their location in the catchment or any factor relating to their establishment or structure, except their total road network.

The patterns of distribution of alien plants in small towns according to land-use type was similar for all alien plant species and for that subset which were also recorded in the regional naturalization database (and thus less reliant on urban-specific conditions and likely to become invasive) in that gardens and low-income areas (also predominantly gardens) accounted for the highest species richness. This echoes many other studies and is widely attributed to the ornamental horticulture pathway (e.g. Marco et al. 2008; Lubbe et al. 2011; Ööpik et al. 2013; Aronson et al. 2014a,b). Each urban property represents a palate which a landowner is free to populate with whatever suite of species they desire, can afford, or can source. The recent rise of internet-based trade widens this potential species pool further and reduces sourcing constraints that might otherwise exist (Lenda et al. 2014). At the scale of an urban garden, landowners can alter microclimatic, soil and disturbance regimes to suit particular plants of their selection. One might thus find a sub-tropical-inspired garden immediately adjacent to a xeric, succulent-themed one. Therefore, our finding that total road length was the only significant variable for predicting the number of alien as well as invasive plant species in a given town might simply be a function of the fact that towns with longer road networks have more gardens to survey. It is worth noting that the same pattern of increasing invasive species numbers with increasing road network length was also recorded on a global scale by Sharma et al. (2010).

In terms of survey results by road type, patterns for all alien and invasive alien plant species were again similar to each other, with the bulk of within-town diversity recorded in the centre of towns (parallel and perpendicular roads) and in the adjacent low-income areas. Although for most towns, the Main Road was also located, at least partially, in the centre of the urban sprawl, the typically high degree of commercial activity along these transects resulted in rather hostile conditions for plants. Hence these roads tended to show a low representation of overall plant species diversity. Similarly, urban edge and main access roads contained relatively low alien and invasive plant diversity and can be de-prioritised in future surveys where time and cost implications limit expandable search effort for comprehensive sampling.

The high numbers of both alien and invasive alien plant species recorded in the low-income areas of the towns surveyed is somewhat contrary to other studies considering socio-economic influence on alien and invasive species (Sharma et al. 2010 for a global study and Santos et al. 2011 for a regional example from Portugal). While these papers postulate that more affluent countries or communities can afford a larger selection of plants, leading to higher overall numbers of the invasive subset, we propose that low-income conditions favour the selection of invasive species in our context. It is precisely this inability to purchase, cultivate or maintain a wide range of diverse species that drives people in these areas to select plants which are already at least naturalizing in the area (thus essentially providing free propagules of plants demonstrably capable of surviving in the region). This would also bias species selection towards vegetatively reproductive (and thus more likely invasive) species (Marco et al. 2010). Species able to survive in this high-disturbance, low-maintenance environment are at once locally sought-after as well as more likely capable of being successful (invasive) outside the town's urban sprawl.

Interestingly, not only were all towns shown to be similarly capable of hosting a number of alien and invasive plant species, but the very high degree of nestedness between all sites surveyed indicates that the same suite of species is involved across the catchment. This means that alien plant species heterogeneity is high in each town, but that the regional urban alien flora is fairly homogenous. The pattern observed in the Berg River catchment is thus similar to that reported by Marco et al. (2008) who reflected the juxtaposition of the opposite social attitudes of conformity verses individualism. For this study, those forces appear to be scale-dependant with small-scale within-town individualism (heterogeneity) juxtaposing large-scale between-town conformity (homogeneity). Almost none of these small towns had their own formal nursery trade through which gardeners could select species, so this pattern also indicates the importance of human-mediated, long-jump dispersal where propagules are swapped, traded or otherwise moved between towns in the region (as recorded in China by Horvitz et al. 2017) and/or between larger towns in the area with formal nurseries. This observed regional homogeneity might also reflect historically small selection available through the horticultural trade (as observed by Smith et al. 2006), something that the rise in internet trading is likely changing (Lenda et al. 2014). Given that most gardeners have been found to select alien over indigenous species worldwide (Pyšek 1998; Lubbe et al. 2011; Ööpik et al. 2013; Cubino et al. 2015), one can assume an increasing invasion debt build-up within small towns and thus increasing threat of future invasions emanating from them.

2.5 Conclusion:

Our results show that plant surveys of small urban areas focussing on locating and reporting on invasive species (*inter alia* for municipal NEM:BA compliance) should concentrate on gardens and low-income areas to maximise the compilation of information for the lowest effort.

In order to gain the most amount of information about that town’s invasive plant species component with the least amount of search effort, municipal managers undertaking surveys in their urban areas should design their search to focus on roads in the urban centre (parallel and perpendicular to the main road, while not including the main road itself). It would also be beneficial to survey a portion of the associated low-income area. Species recorded in such a survey should be checked against records from regional naturalization databases (where available or reliable) to help prioritise management effort in the urban portions of municipalities.

Because within-town diversity resides chiefly in gardens, each of which may host substantially different species from adjacent gardens, the more gardens that are surveyed, the greater the confidence will be for achieving an accurate assessment of the town’s total alien plant species component.

Acknowledgements

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Supplementary Table 2.1: Results of relationships between a range of variables from 11 small towns within the Berg River catchment, South Africa, and the number of alien plant species observed in our surveys of these towns (see Table 1). * denotes statistically significant results.

	Estimate	Standard Error	Z value	*p*	df	AIC
Total road length (km)	2.824e-06	4.764e-07	5.929	*P*<0.001*	10	131.56
Population density (persons/km^2)	3.253e-05	1.727e-05	1.884	*P*<0.1	9	130.69
Age (years)	-0.0005715	0.0006620	-0.863	*P*=0.388	8	110.17

Chapter 3:

Small urban centres as launching sites for plant invasions in natural areas: insights from South Africa

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Authors: Phil McLean[1,2]Laure Gallien[1], Mirijam Gaertner[1,3], John R. U. Wilson[1,2] & David M. Richardson[1]

Address: [1] Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.
[2]South African National Biodiversity Institute, Kirstenbosch National Botanical Gardens, Private Bag X7, Claremont 7735, South Africa.
[3] Nürtingen-Geislingen University of Applied Sciences (HFWU), Schelmenwasen 4-8, 72622 Nürtingen, Germany.

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Contribution of each author:
PM, DMR, JRUW & MG: Planning and design of the study.
PM: Compiled databases, undertook statistical analyses, and led the writing.
DMR: Commented on the manuscript and improved the writing.
JRUW: Commented on the manuscript and provided statistical advice.
MG: Provided comments on the manuscript.
LG: Commented on the manuscript and provided statistical advice.

Abstract

Alien species are often first introduced to urban areas, so it is unsurprising that towns and cities are often hotspots for invasions. However, while large cities are usually the first sites of introduction, small towns are more numerous and have a greater chance of launching invasions into natural areas as they have proportionally larger interfaces with their surroundings. In this paper we develop a set of scenarios as hypotheses to explore the role of small towns in facilitating within-country dispersal of alien plants. In particular, we developed ten scenarios for how introductions to small towns, agricultural and natural areas can lead to landscape-scale invasions.

We tested a part of these scenarios using a case study of a highly invaded region in South Africa (the Berg River catchment in the Western Cape). We specifically investigated the main plant invasion routes between 12 small towns and their surrounding agricultural and natural areas. This was accomplished by conducting urban-specific alien plant surveys in towns, then comparing these results to regional databases of naturalizing and/or invasive plant records.

Many of the alien plants found in urban areas were listed as invasive or naturalized in the catchment (over 30% of the total alien species pool). Despite marked environmental gradients across the study area, we found no relationships between the alien plant species richness in towns and climatic variables or with levels of anthropogenic disturbances. All towns hosted large numbers of invasive plant species and nearly half of the alien species found in towns were naturalized or invasive in surrounding areas. The likelihood of alien plants being naturalized or invasive outside urban areas increased in proportion to their local abundance in towns and if they were tall and woody. Ornamental horticulture was the main reason for introduction of these alien species (69%).

Small towns can and do harbour significant populations of plant taxa that are able to spread to surrounding natural areas to launch invasions. In the catchment studied here, this route accounts for just over a third of the total number of alien plants found in towns. Comparing lists of species from urban alien plant surveys with those from naturalization records for the region is a useful protocol for identifying species which may be moving along the introduction-naturalization-invasion continuum.

3.1 Introduction

Biological invasions are a major cause of the loss of global biodiversity and understanding the patterns and processes of invasions is becoming increasingly important. A positive relationship between alien species richness and human population density has been reported for many parts of the world (van Rensburg et al. 2009; Spear et al. 2013; Aronson et al. 2014a; Aronson et al. 2014b). Urban areas host many alien species, and act as important foci from which some alien species spread and invade surrounding natural areas (Alston and Richardson 2006; Gelbard and Belnap 2003; Dostálek et al. 2014). For example, Cilliers et al. (2008) found similar patterns of invasion of species from urban areas into surrounding fragmented grassland in both southern Africa and Australia, while Dodd et al. (2016) showed how most records of first naturalization occurred near major population centres.

Horticulture is an important pathway for the introduction and dissemination of alien plants around the world (Hodkinson and Thompson 1997; Reichard and White 2001; Richardson et al. 2003; Dehnen-Schmutz et al. 2007a,b; Foxcroft et al. 2008; Lambdon et al. 2008). This pathway explains much of the number and diversity of alien plant species in cities (Sanz-Elorza et al. 2008; Marco et al. 2010; Asmus and Rapson 2014).

Horticultural plants are largely protected from natural disturbance regimes and large herbivores while in cultivation. However, the surrounding urban areas are often disturbed, which provides opportunities for recruitment (Alston and Richardson 2006) - the so-called weed-shaped hole (Buckley et al. 2007). Moreover, edaphic factors like soil fertility, acidity and (seasonal) moisture content are often also controlled and modified in urban environments. Finally, plants are moved to many different localities by gardeners who buy from suppliers and trade, share or otherwise move propagules or whole plants, i.e. there is significant human-mediated dispersal similar to the "long-jump dispersal" observed in China by Horvitz et al. (2017).

Marco et al. (2010) demonstrated the propensity of certain plant species to begin invading natural areas surrounding urban dwellings based on their growth characteristics and their position in the garden. The closer plants were to the outer edge of gardens, the more likely they were to "jump the fence" and escape into natural and semi-natural habitats. Key traits such as the capacity to reproduce vegetatively, and tolerance of dry soils and high pH levels also facilitated invasiveness of some species. Similarly, human movements within and out of urban spaces facilitate the dispersal of propagules to the surrounding natural areas, particularly seeds which can be transported an appreciable distance by cars (Zwaenepoel et al. 2006; von der Lippe and Kowarik 2008; von der Lippe et al. 2013).

There is, however, an important distinction to be made between the size and location of urban areas and the role such areas play as launching sites for invasions. Large cities typically have much greater alien species richness than small rural towns and villages, and are often the first places in a country to which a plant is introduced (Pyšek 1998; Vitousek et al. 1997a; Dodd et al. 2016). However, most large cities have a relatively small interface between urban and wildland ecosystems (though there are some notable exceptions, e.g. the City of Brasilia in Brazil, which is surrounded by a national park and three other large protected areas). In small rural towns and villages all gardens are relatively close to the urban edge. Despite this obvious risk and the fact that small towns outnumber large urban centres, most studies conducted on plant invasions in urban areas have focussed on big cities (e.g. Alston and Richardson 2006; Lambdon et al. 2008; Botham et al. 2009; Aronson et al. 2014; Lenda et al. 2014).

Although the requirements for establishment, growth and reproduction for many alien species are met in urban ecosystems, the opportunities for spread (i.e. invasion) to areas outside the urban environment are often limited, especially where conditions across the interface between urban and surrounding areas differ significantly. As a result, many introduced plant species fail to survive in new environments outside active cultivation (Reichard and White 2001). This is very important in areas such as the Western Cape of South Africa, where areas outside urban centres experience regular intense fires, often have nutrient poor soils, and are subjected to high temperatures and drought in summer (Bugan et al. 2012). A large cohort of naturalizing plants and/or listed “weeds” (i.e. problem plants) found primarily or only in urban areas would suggest that those plants were unable to spread from there into the surrounding natural areas. If this were the case, one might argue to ignore the contribution of urban environments to invasions in surrounding areas. Alternatively, the same species might represent a future landscape invader, i.e. are part of the invasion debt (Rouget et al. 2016). We formalise these different hypotheses as a set of scenarios.

3.1.1 Invasion scenarios

Alien plants can be introduced directly to one or several urban areas, agricultural fields, or natural ecosystems. From there, they can either remain in the initial habitat or naturalize and invade a different habitat type. Here we consider ten scenarios for the potential sequence of arrival and movement of alien plant species within towns and from towns into surrounding habitats (Fig. 3.1). Each scenario corresponds to categories of invasion status following the proposed unified framework for biological invasions (Blackburn et al. 2011).

Our aim was to gain an understanding of the type and abundance of alien plant species found within small urban centres using our study system (the Berg River Catchment, South Africa) as a case study. We also investigated regional databases of invasive plant records and records of plant naturalization, both from outside urban areas. We then analyse and interpret species' records at various intersections between these datasets, and infer directionality of spread based on literature regarding each species' introduction history. The aforementioned scenarios explain the options to plant arrival and spread and we address several of these using data from our case study area. The most important of these is Scenario 3 (those potential future invaders that have 'jumped the garden fence') since these plants will have the largest management implications.

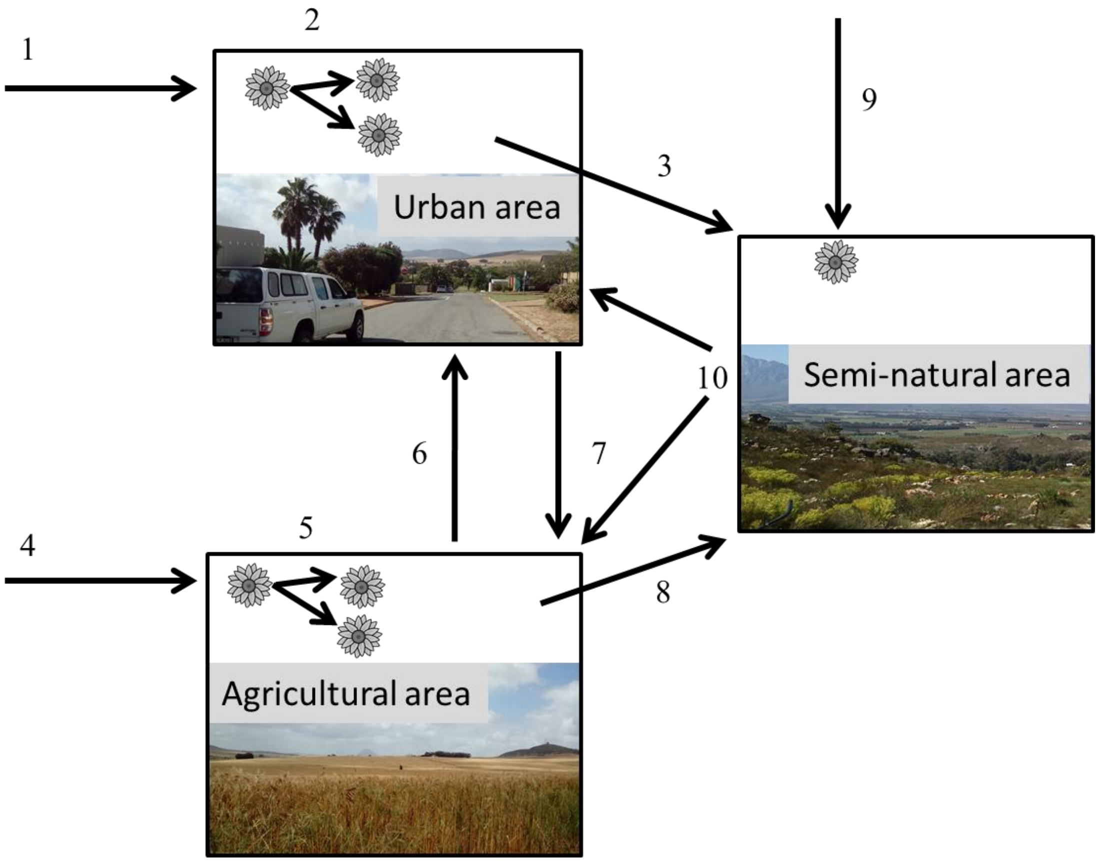

Fig. 3.1. Scenarios for the different routes of introduction and subsequent spread of alien plants between small towns and surrounding agricultural and natural areas. Usage of all terms and concepts relating to introduction, naturalization and invasion conforms with the definitions proposed by Richardson et al. (2000, 2011). Invasion status is defined as per the unified framework for biological invasions (Blackburn et al. 2011), except that we relax the stipulation in the unified framework that naturalized (regularly reproducing) or invasive (spreading over substantial distances) taxa (categories C-E in the unified framework) need to be in "wild" environments.

Scenario	Description	Invasion status	Implications for management
1: Urban only, not naturalized	Taxa introduced directly into a town and remain confined to this space (i.e. no naturalized populations).	B2	Could contribute to the invasion debt, but if there is a mechanism known to restrict reproduction could be on a permitted list.
2: Urban only, naturalized	Taxa introduced into towns, able to naturalize within this space, but not outside of the altered conditions that the urban environment provides.	C2-E	Unless a mechanism is known to prevent naturalization in the wild, should be considered as a future environmental invader. Regardless of invasiveness, there might be socio-economic impacts that justify management.

Scenario	Description	Invasion status	Implications for management
3: Jumped the garden fence	Taxa introduced into towns and able to naturalize and spread into surrounding natural areas.	D1-E	Environmental impacts need to be assessed, and potentially measures implemented to prevent spread from towns, or to prohibit plantings in towns.
4: Agricultural only, not naturalized	Taxa introduced into agricultural areas that remain confined to these altered environments.	B2	As for scenario 1
5: Agricultural only, naturalized	Taxa introduced into agricultural areas able to naturalize, but remain confined to the agricultural landscape.	C2-E	As for scenario 2
6: Agro-Urban invader	Taxa originating from the agricultural space but able to naturalize and spread into nearby urban areas.	D1-E	As for scenario 2, but with greater concern for impacts.
7: Urban-Agro invader	Taxa naturalized in towns and subsequently spreading into agricultural areas.	D1-E	As for scenario 2, but with greater concern for impacts.
8: Jumped the farm fence	Taxa introduced into agricultural areas and able to naturalize and spread in natural areas.	D1-E	As for scenario 3
9: Environmental introductions	Taxa introduced directly into natural areas.	B3-E	An invasive risk analysis should have been conducted prior to release, and should be done retrospectively if not.
10: Environmental introductions spreading to agricultural and/or urban areas	Taxa introduced directly into natural areas able to naturalize and spread into agricultural and/or urban areas.	E	This scenario describes successful, established invaders. These may or may not be receiving management attention in natural areas. If so, effort should be made to remove any ingress into urban areas to prevent these areas acting as refugia for future re-invasion of surrounding natural areas.

3.2 Materials and methods

3.2.1 Study area

We sought a study system with a large number of towns of varying sizes close to natural areas for which comprehensive data on alien plant occurrence were available. We selected the Berg River Catchment in South Africa's Western Cape province (Fig. 2.1). It is bounded by the high (over 1500 m.a.s.l.) Jonkershoek and Hottentot's Holland mountains in the south and east and the Atlantic Ocean in the northwest. The Berg River is approximately 294 km long. The predominantly winter rainfall over the catchment varies from less than 300 mm yr^{-1} at the mouth to 3200 mm yr^{-1} in the mountainous south. The soils are typically nutrient-poor, reflecting the underlying geology of quartzites and sandstone derived from the Cape Supergroup in the upper reaches and Cape Granites in the middle reaches with more recent sediment deposits near the coast (de Villiers, 2007). The catchment supports dryland agriculture (mainly wheat) in the northern and western sectors, while irrigated soft fruit forms the bulk of agriculture in the wetter south and adjacent to the mountain ranges. Natural areas comprise mostly fynbos shrublands with high species diversity and levels of endemism. Many rare native plant species in this region are threatened with extinction, due to their very narrow range of environmental tolerance coupled with expanding urban areas and pressure from invasive alien plants. Riparian habitats along the Berg River are dominated by alien trees and shrubs (Tererai et al. 2013). Within this catchment 457 species of native plants are listed as threatened of which 270 are either Endangered or Critically Endangered (South African National Biodiversity Institute 2006).

Another reason for selecting this catchment as study domain was that it is a major water source for the urban and agricultural concerns in the area, most notably the city of Cape Town which lies c. 70 km to the southwest, just outside the catchment. This means there is substantial interest in environmental issues in the area, including the management of invasive species (Ruwanza et al. 2013; Fill et al. 2017). Two organizations conduct or coordinate most invasive alien plant management operations in the catchment: the Working for Water (WfW) programme of the national Department of Environmental Affairs, and CapeNature (the provincial conservation agency in the Western Cape). WfW is a government initiative that employs mainly unskilled labour to control invasive plants while simultaneously creating jobs (van Wilgen and Wannenburgh 2016). CapeNature is the entity mandated to manage provincial protected areas, including the control of invasive species therein. Relatively good data on the distribution of invasive plants exist at the landscape scale for this catchment, mainly from the management plans and other records of the aforementioned organizations and from the Southern African Plant Invader Atlas (SAPIA; for details see Henderson and Wilson 2017).

Within this geographical area are 28 urban areas (see Supplementary Table 3.1) that range in population size from 330 to just over 100,000 with population densities ranging from 10 to 5,000 people/km^2.

For the purposes of this study we used a population-dependant settlement hierarchy (Doxiadis 1968) and thus defined 'small towns' as those containing between 1,000 and 15,000 inhabitants (as defined by census information from 2011 available from Statistics South Africa). This gave us a set of twelve towns that varied in population size, density, number of households and household size distributed throughout the catchment, from coastal (Velddrif) to mountainous areas (Pniel) (Supplementary Table 3.1).

3.2.2 Plant species data for towns

Each selected small town was surveyed to determine alien plant species richness and abundance. Based on the results of a previous systematic survey of one of the towns (that found 84% of alien plant species recorded were present in gardens and along roadsides; P. McLean, unpubl. data), we developed a sampling strategy to estimate the alien plant species richness in each town. Streets were treated as transects and the following zones were surveyed in every town: (i) the main (commercial) road of the town, (ii) the main access road into/out of the town (if this was different to the above), (iii) at least one road parallel to the main road, (iv) at least one road perpendicular to the main road, (v) one urban edge road (where houses are found along one side of the road, while the other is open to the environment – preferably not agricultural), and (vi) one road in the low income neighbourhood.

Along each transect we recorded and identified all alien plants. Spreading plants and those with multiple stems or creepers were measured using a square-metre cover estimate, with 1 m^2 of groundcover taken as equal to one plant in the analyses. All scientific names were checked against The Plant List (Version 1.1, 2016; accessed October 2016). Some individuals of the genera *Eucalyptus*, *Melaleuca* (including *Callistemon*) and *Pinus*, and some horticultural plants (e.g. *Bougainvillea*, *Lavandula* and *Rosa* species) could not always be identified to species level. This was because species in these genera often require one to be in very close proximity to an individual plant to observe the minute or subtle differences in morphology (flower, fruit, leaf and/or bark) that are required for a positive identification. Such close access was often not possible at the study sites as many plants are on access-controlled private property. We therefore considered these groups at the genus level only to avoid representational biases.

The reason for introduction of each species recorded was sourced from local literature on invasive and problem plants in the region (Henderson 2001; Bromilow 2010). These were: (1) Horticulture (all ornamental species); (2) Agricultural (including species used in agriculture but not as a harvestable crop, e.g. trees used as wind breaks but not agroforestry); (3) Agroforestry (in this broad category we included species originally imported for dune stabilisation); (4) Accidental (typically contaminants or hitchhikers). We also categorised species into different growth forms: (1) Tall woody (adults over 2m in height, woody stems); (2) Short woody (adults under 2m in height, woody stems); (3) Herbaceous (any height but lacking woody stems); (4) Succulent; (5) Creeper (scrambling or climbing, but not self-supporting); (6) Aquatic; (7) Grass; and (8) Palm.

3.2.3 Plant species data for natural areas in the catchment

Catchment-wide alien plant data were collated from existing databases from five independent sources: (i) Southern African Plant Invaders Atlas (SAPIA) records (accessed 9 June 2016), (ii) clearing records from the Working for Water program (WfW) (accessed 13 September 2016) which include data from Provincial and National Departments of Environmental Affairs as well as regional NGOs and municipal contractors acting as implementing/clearing agents for WfW, (iii) iSpot Citizen Science network (accessed 1 November 2016), (iv) clearing records from SANBI's Invasive Species Programme (Wilson et al. 2013), and(v) CapeNature (for protected areas only; accessed 18 August 2016). Only records from within the boundary of the Berg River catchment were used.

We generated a conceptual Venn diagram (Fig. 3.2) which graphically explains the contents of each dataset and shows which intersections we anticipated to be most useful in determining the extent of the scenarios investigated in this research.

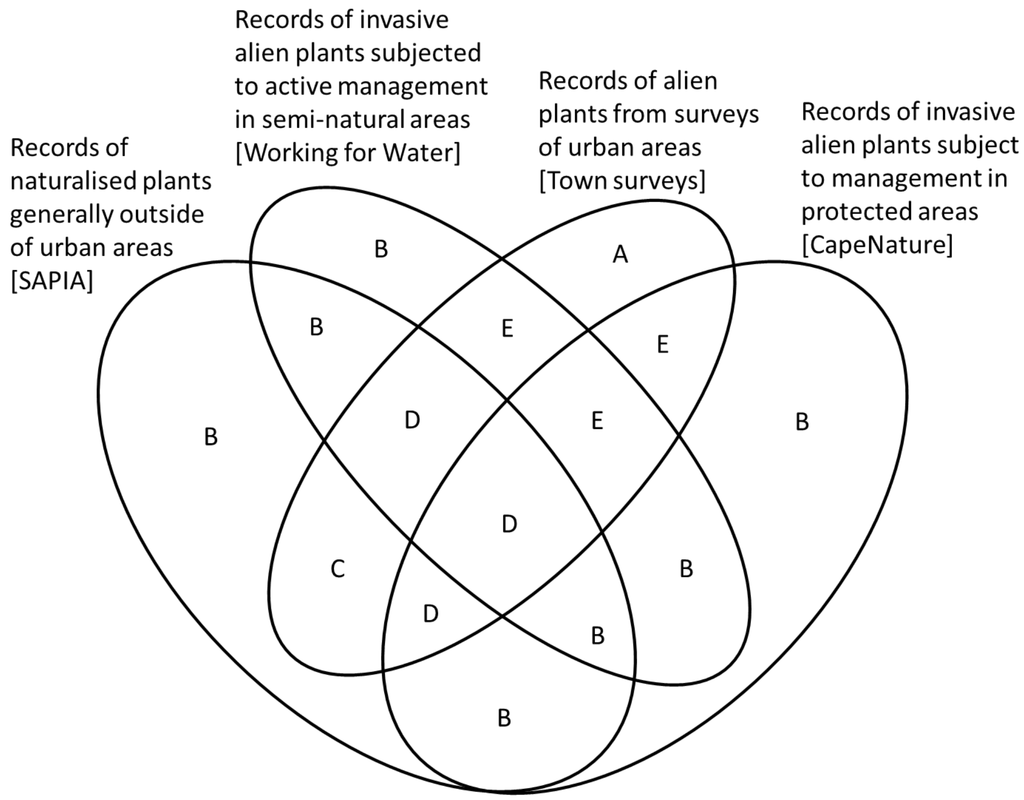

Fig. 3.2. Conceptual diagram indicating the composition of information within each of the datasets used in this study while explaining the key intersections between these datasets and how this relates to the set of scenarios in Fig. 3.1.
Intersection A: Species recorded within town surveys only. These correspond with Scenario 1 plants from Fig. 3.1.
Intersection B: Species recorded only within the dataset of naturalized species outside of urban areas. Species occurring in this category correspond with Scenario 8 and 9 from Fig. 3.1.
Intersection C: Species recorded in both town survey data and records of naturalized species outside of towns but not recorded within either dataset of invasive plants subject to management in semi-natural areas. These species correspond with Scenario 3 in Fig. 3.1.
Intersection D: Species recorded in town survey data, regional naturalization records as well as either (or both) datasets for invasive plants subject to management actions. These species are established invaders and correspond with Scenario 6, 8 and 10 in Fig. 3.1.
Intersection E: Species recorded in towns and regional invasive species datasets but are not recorded in the regional naturalization dataset. These are Scenario 6 species which have either spread into towns only or are yet to be detected in natural areas.

3.2.4 Analysis

To determine the similarity of the catchment-wide alien plant data to the data from our survey of urban areas, we used Venn diagrams with the same format as Fig. 3.2. We did this both for all alien plant species, and for the alien plants that were most frequently encountered in towns (i.e. those that had 100 or more records, 149 species in total). This level of high abundance across all towns indicates either frequent planting or that these species are naturalized in this habitat. Either way, species in our “most abundant” set are most likely contributing the greatest propagule pressure into the surrounding environment.

We ran generalised linear models to investigate how alien species richness per town is affected by climate and anthropogenic disturbance. Climatic variables were extracted from BioClim, an online global data resource with a spatial resolution of 1 km^2 (WorldClim version 1.4, 2016). We selected those parameters in the region which vary most across the catchment: Bio1 (mean annual temperature) and Bio12 (annual precipitation). The Human Footprint index was used as a proxy for anthropogenic disturbance. It is an indicator of the degree of human-mediated disturbances in an area ranging from 0 (*wild*) to 100 (*highly disturbed by humans*). It is derived from global records of population pressures (i.e. population density), human infrastructure (i.e. urban areas), and transport access (i.e. roads and railroads), and was obtained for the region from the SEDAC database (Sanderson et al. 2002). This index has proved useful in modelling invasive plant distribution in southern Africa (e.g. Richardson et al. 2010).

We also analysed each town in terms of the proportion of that town’s total alien taxon list for which there was evidence of naturalization elsewhere in the catchment (i.e. inclusion in

SAPIA or one of the clearing agencies' databases; Intersection D from Fig. 3.2). The rationale for this was that such a comparison would indicate whether a particular town showed a different pattern of hosting risky taxa, thereby flagging these towns for management consideration.

3.3 Results

We noted 28609 records of alien plants, representing 365 species and 64 genera (Appendix B). This was 14 and 9 times more than the total number of species in databases maintained by the management agencies (26 and 40 species for CapeNature and WfW respectively) and is also higher than the SAPIA database (regional naturalization records) for the study area (216 species) (Fig. 3.3). We recorded between 78 and 121 alien plant taxa per town, with between a third and a half of the taxa per town having been recorded as naturalized in the catchment (see Supplementary Table 3.1).

Fig. 3.3. Alien plant species richness per quarter-degree grid cell as recorded from three different data sets and our study survey of 12 small towns in the Berg River catchment (South Africa). SAPIA is the Southern African Plant Invader Atlas and consists of records of naturalized species predominantly outside urban areas. CapeNature is the provincial nature conservation authority and has records of invasive plants subject to management intervention within protected areas. Working for Water (WfW) is a national program for invasive plant management which operates predominantly in areas of strategic importance as water catchments. Species listed in the WfW database are subject to management intervention in semi-natural areas outside of urban development.
Boxes represent the upper and lower quartiles of each dataset with the median shown by the thick central line. The whiskers extend to the maximum and minimum data points for each dataset.

In total across all datasets, 456 alien plant taxa were recorded in the catchment (Fig. 3.4a). Most of these species (448 species; 98%) were recorded in either the town surveys or in regional naturalization records (SAPIA). The data sets from management agencies reflect their focus on the relatively few species that cause landscape-scale impacts (i.e. 46 species threating ecosystems services such as water supply; Fig. 3.4a). The 15 taxa represented in all catchment databases as well as in our town survey are well-known and well-established invading plants in the region: *Acacia baileyana*, *A. cyclops*, *A. longifolia*, *A. mearnsii*, *A. melanoxylon*, *A. pycnantha*, *A. saligna*, *Eucalyptus* spp., *Lantana camara*, *Paraserianthes lophantha*, *Pinus* spp., *Rubus* spp., *Sesbania punicea*, *Solanum mauritianum*, and *Xanthium strumarium* (Wilson et al. 2014). Of these invaders, only *Rubus* species have a direct link to agriculture and only *L. camara* (with the added possibility of some *Eucalyptus* and *Pinus* species in the past) have any horticultural connection. The group of species recorded in the town-survey, SAPIA and WfW datasets (but not in CapeNature) include the grass species *Arundo donax*, *Cortaderia selloana*, and *Pennisetum clandestinum*, as well as tree species in the genera *Casuarina*, *Populus* and *Quercus* which are associated with agriculture. WfW records indicate that R 52 million (approximately US$ 4.5 million) was spent on invasive plant clearing efforts on these species in this catchment between 2001 and 2016.

The surveys in the 12 towns revealed 227 alien plant species which are not found in the other datasets, and 105 species that are also listed in SAPIA as being naturalized in the catchment (Fig. 3.4a). The species which are present in towns and in another other data set (thus either listed as naturalizing or invasive somewhere in the study area) account for 38% of the total number of taxa recorded for all towns. Similar trends are apparent if we consider only abundant plant species from towns (i.e. those with 100 or more records; Fig. 3.4b). Seventy (47%) of the most abundant species within towns are either naturalized or invasive in this catchment, and 18 of these are currently receiving active management attention in natural areas of the study catchment.

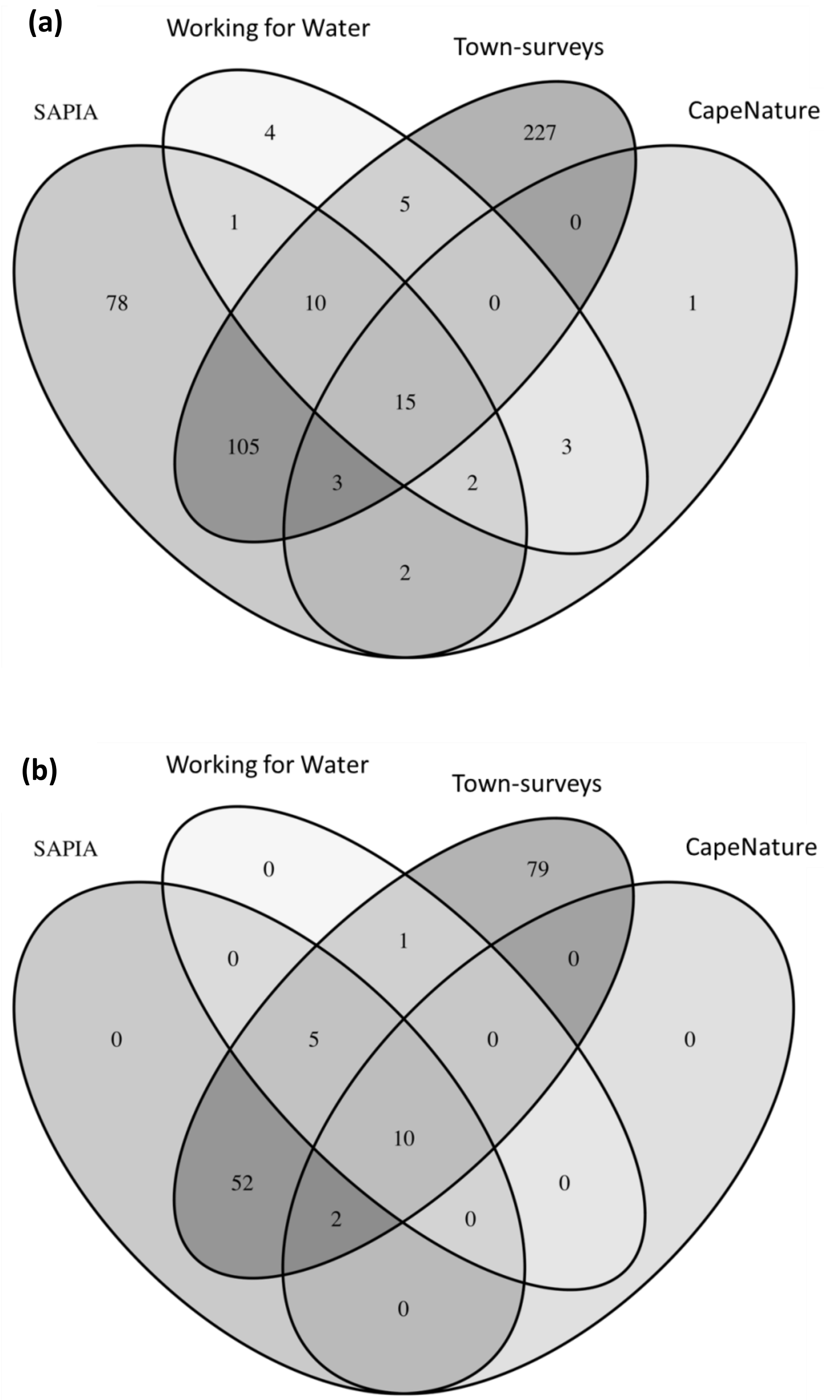

Fig. 3.4. Alien plant taxa recorded within the Berg River Catchment, South Africa. The diagram shows the overlap in numbers of species recorded in four different data sets (SAPIA; Working for Water; CapeNature and the surveys of 12 small towns conducted here). Panel **(a)** shows all 456 species recorded in total across datasets, and panel **(b)** shows a subset of the 149 most abundant alien species of the Town-survey dataset. See Fig. 3.2 for details of what the various intersections between data-sets mean.

Most naturalized taxa were either tall woody (44%) or herbaceous (25%) (Table 3.1). More than two-thirds (65%) of the most abundant naturalized plants in towns were introduced for horticultural or ornamental purposes.

We found no significant relationship between total species counts for towns and any environmental parameter (climate and position in the catchment) or the Human Footprint index (proximity to areas of high human disturbance; Supplementary Fig. 3.1). There was also no significant relationship between these environmental or human disturbance parameters and the proportion of naturalized species in a given town's alien flora (as recognised by the SAPIA database).

The comparison of urban alien plant survey data with records of naturalized as well as invasive populations in the same catchment allow us to revisit and begin to populate the conceptual set of scenarios (Fig. 3.1). The plants which represent Scenario 1 (Intersection A from Fig. 3.2) we called "Urban only, not naturalized"; those 227 species occurred only in the town-surveys dataset (around 50% of all species recorded across all datasets) and include non-reproductive species (e.g. *Rosa* spp.). It also includes a subset of species of Scenario 2 or "Urban only, naturalized", which do naturalize within towns but have not yet been detected outside urban areas (e.g. *Breynia disticha*). Species occurring only in invasive or naturalization records and not in towns (Intersection B in Fig. 3.2) have spread into natural areas from agricultural (therefore not urban) areas (Scenario 8) or were introduced directly into natural areas (Scenario 9, e.g. *Hakea drupacea*). The reason for introduction for each species will explain which scenario applies to which species. The 105 species recorded in both town-surveys and regional naturalization records (SAPIA) are plants which naturalize in towns and in surrounding areas. These species, captured in Scenario 3 (see also Fig. 3.2 Intersection C), are those potential new invaders which have "jumped the garden fence" and include many species that were introduced for horticulture (Table 3.1) (e.g. *Pennisetum setaceum*). Overlap in species' records within towns, regional naturalization as well as regional invasive datasets (Intersection D) indicate that these plants are established invaders in that area and are likely moving from their introduction in agricultural areas (Scenario 6, e.g. *Echium plantagineum*) or from natural areas into agricultural and/or urban areas (Scenario 10, e.g. *Acacia saligna*). Intersection E plants are those few species of Scenario 6 which were introduced into agricultural areas and spread into towns but have remained undetected in natural areas as evidenced by their lack of capture in the regional naturalization database.

Table 3.1. Numbers of taxa introduced for ornamental use and non-ornamental use (divided into six growth forms) for the most abundant taxa in towns that were also represented in the SAPIA data set of naturalized taxa (52 taxa from Fig. 5b).

	Tall Woody	Short Woody	Succulent	Creeper	Grass	Herbaceous	Total
Ornamental taxa	19	2	2	3	1	7	**34**
Non-ornamental taxa	4	1	1	2	4	6	**18**
Total records	**23**	**3**	**3**	**5**	**5**	**13**	**52**

3.4 Discussion

As expected, a large number of alien plant species enter towns via the horticultural or ornamental trade (Scenarios 1 & 2; Table 3.1). We also showed that 47% of the most abundant alien species in towns have established naturalized populations outside urban areas (Scenario 3). While some species from this group reflect those with an agricultural origin which are spreading into urban areas (Scenario 6, e.g. *Echium plantagineum*), the majority of the records are of plants which were introduced for ornamental/horticultural purposes (65% from Table 3.1). This implies they were introduced first into urban environments and their regional naturalization records are an indication of their subsequent spread from urban environments into natural environments. Many authors have highlighted the risk of horticulture as a pathway of invasion (e.g. Hodkinson and Thompson 1997; Reichard and White 2001; Dehnen-Schmutz et al. 2007a,b; Foxcroft et al. 2008; Lambdon et al. 2008; Zenni 2014). Moreover, the invasion risk posed by horticultural trade has recently increased for many reasons, including the expansion in trade through the internet (Lenda et al. 2014) and species selection shifting towards more dry-adapted species in response to climate change. This could be a problem in future as dry-adapted species are more likely to naturalize (Marco et al. 2010). Our results confirm these findings (for this catchment) and suggest that the predominant route of invasion in natural areas is that of introduction to towns, and subsequent spread to natural areas and agroecosystems (Scenario 3 from Fig. 3.1; also Intersection C from Fig. 3.2). This was somewhat surprising given the harsh environmental conditions in this region, so it would be interesting to repeat this study in other parts of the world. We predict less pronounced patterns in harsher regions such as desert settlements and more pronounced in regions where conditions outside urban settlements are more benign (e.g. tropical regions). The pattern is probably an unwanted side-effect of the practice of preferentially selecting alien garden plant species that are pre-adapted to local environmental conditions.

Our results provide support for previous work that has shown that alien plant species richness is considerably higher within urban settings than in natural areas (Fig. 3.3). This was expected given the well-established finding that alien species diversity is positively correlated with human population density (van Rensburg et al. 2009; Spear et al. 2013;

Aronson et al. 2014a,b). One would expect a high diversity of introduced plants for the mix of horticultural and ornamental use (e.g. roses) and small-scale agricultural use (e.g. lemon trees) to be found in urban ecosystems. We also note how many of these species (227) were only recorded in town surveys (Fig. 3.4a). These species may require a high degree of human intervention to survive conditions which may be dissimilar to their natural range, or they may even be sterile. This set is considered to be (currently) confined to this modified environment since they do not appear in lists of species that are the focus of agencies involved with invasive plant management (WfW or CapeNature) or in regional records of naturalization (SAPIA). Even if some of these species are naturalized in urban environments, this does not guarantee that they will be able to colonise natural and semi-natural areas outside these urban centres (Reichard and White 2001). Some species in this set are listed invasive taxa in South Africa (e.g. *Tecoma stans*). The fact that they do not yet appear in any of the other datasets implies either that the conditions outside of the urban environments are unsuitable for them to establish, or that naturalized populations have yet to be detected in this catchment. Ideally, a risk assessment should be conducted on these species to determine which could spread.

A large number of species (105) occurred in the towns and were recorded in SAPIA, but do not appear on the WfW or CapeNature lists (Intersection C from Fig 3.3). Naturalized species confined to human-dominated ecosystems are underrepresented in SAPIA (L. Henderson, pers. comm.). This means that SAPIA records for our study area indicate records of naturalization mostly outside of towns - in natural and semi-natural parts of the landscape. Therefore, these 105 species are plants which are found in towns but also have recorded naturalized populations outside of towns in this region. Such species can spread from towns into the surrounding areas notwithstanding the environmental challenges posed by the Cape Floristic Region (fire-prone, summer drought, nutrient poor soils). These species account for 23% of the total species list for the catchment and are identified as likely new invaders (Scenario 3). They thus constitute spread debt as defined by Rouget et al. (2016) and should be of interest to managers in the area. It is important to note that these 105 naturalizing alien species are in fact an addition to the 46 species already being treated as invasive in this region (as recognised by their inclusion in CapeNature or Working for Water datasets). This makes the potential invasive species component over 33% of the total recorded alien species for this catchment, which is similar to findings by Tait et al. (2005) for Adelaide and Kowarik et al. (2013) for Berlin, but a little surprising here given the fairly harsh environment.

The finding that more than 70% of the listed invasive species that are receiving expensive management attention at the catchment scale are also found within towns is problematic (Intersection D in Fig. 3.2). These town-based populations are likely to cause impact not only in the towns, but could also be undermining successful long-term landscape-level clearing operations by providing foci for propagule production and dispersal and therefore re-invasion.

When abundance of plants is considered, the proportion of potentially invasive species (Intersection C in Fig. 3.2; captured in the town survey data and SAPIA) is much higher (47%, 52 species) than when considering all species, regardless of their abundances (23%; Fig. 3.4b). These 52 abundant alien plants are thus of particular concern given their proven ability to form naturalized populations outside urban areas in this catchment. Examples of such species in the study area are *Syzygium paniculatum, Schinus terebinthifolius* (both tall woody species), *Bougainvillea sp.* (short woody), *Catharantheus roseus* (herbaceous), *Avena fatua* (grass), and *Agave americana* (succulent). These findings confirm that the invasive species component within these towns is much greater than was assumed, as is the propagule pressure being exerted by small towns into their surroundings.

Trees and shrubs account for many widespread invasions worldwide, and many species have major impacts (Pyšek et al. 2009; Jarošík et al. 2011; Richardson and Rejmánek 2011). Therefore the pattern of dominance by tall woody species in the invasive component of these most abundant plants (Table 3.1) confirms findings by Kowarik et al. (2013) from Berlin and should raise concern here because the same growth form also accounts for the majority of species that are currently being targeted for management in natural areas in this catchment. Many (65%) of these most abundant naturalized species were introduced for horticulture. This highlights the major importance of this pathway in shaping the invasive species component within these small towns, which agrees with findings of other studies (Downey and Glanznig 2006; Dehnen-Schmutz 2007a,b; Foxcroft et al. 2008; Sanz-Elorza et al. 2008; Marco et al. 2010; Asmus and Rapson 2014; Mayer et al. 2017).

We expected abiotic gradients within the catchment to reveal differences in a given town's ability to host a suite of potentially invasive plant species (Pyšek 1998; Lososová et al. 2011). We found no significant correlates between species richness and either Human Footprint Index, mean annual temperature or annual precipitation at a catchment level (Supplementary Fig. 3.1). This suggests that, within our study area, all urban environments can harbour a suite of species which can naturalize within the same geographical area.

Indeed, a third to a half of all urban alien plant species in each town were also recorded in regional naturalization records (Supplementary Table 3.1), similar to findings from urban areas in New Zealand (Asmus and Rapson 2014). In other words, our data show that, irrespective of position in the catchment, surrounding environmental conditions or measures of human impact, all towns harbour a similarly high proportion of potentially invasive species, which supports our assertion that small towns act as launching pads of invasions into surrounding areas.

Seebens et al. (2017) found no saturation in the accumulation of alien species across the world. The lack of saturation is also evident at the catchment scale in our study. If similar results emerge from studies of urban areas in other catchments, urban floristic surveys could be an important way of locating potential new invaders and flagging species for early management attention. Risk analyses or assessments of invasion debt (Rouget et al. 2016) are needed to determine which naturalized species need to be targeted for clearing within towns before they begin spreading to surrounding areas. Data for our study area show that tall woody species introduced for horticulture and/or as ornamentals are the most likely to be able to naturalize and spread. Analyses such as those outlined in this paper are needed to elucidate within-country pathways of dispersal of alien plants to provide guidelines for management strategies.

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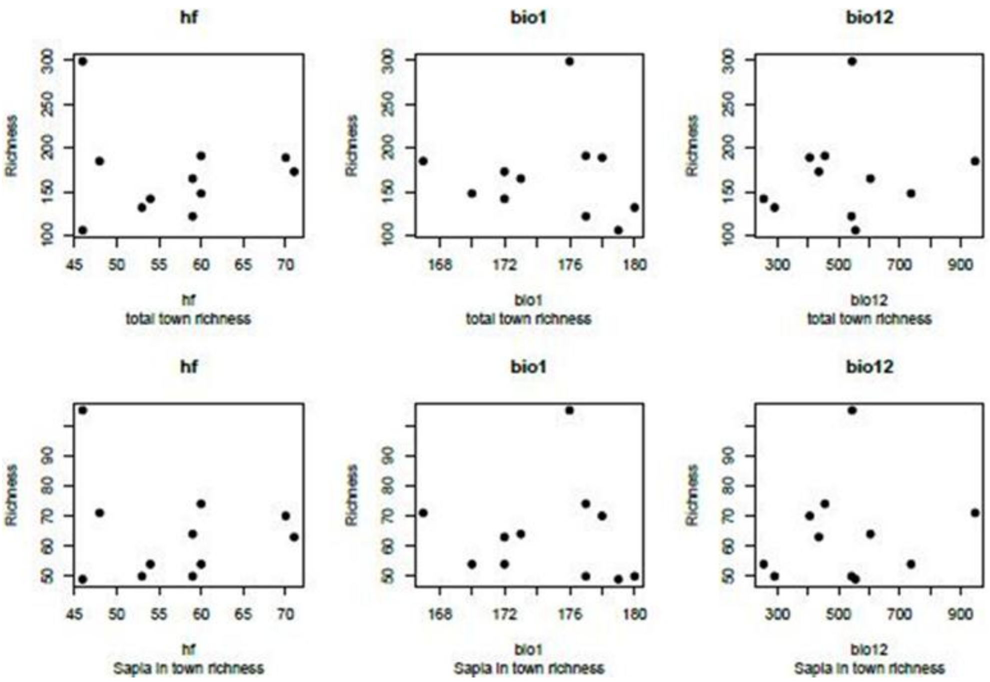
Supplementary Table 3.1 List of towns located within the Berg River Catchment. The table indicates the total population, population density, number of households and the average household size for each of the towns according to StatsSA census information from 2011. Towns surveyed for this study are indicated with an *. For these towns we indicate the total number of alien species observed from our urban plant surveys as well as the number and proportion of these species which are also included in the regional naturalization database (SAPIA).
Note: No population data were available for the small hamlet of Hermon due to its inclusion in a neighbouring region.

Town	Population	Population Density (people/km^2)	Total number of species	Number and proportion of naturalized species
Aurora	578	356		
Darling	1 073	147		
De Hoek	330	11		
Franschhoek	17 556	2 491		
Geodverwagt	1 979	663		
Gouda *	3 441	450	88	37 (42.0%)
Hermon *	**nd**	**nd**	78	36 (46.2%)
Hopefield *	6 460	199	85	34 (40.0%)
Koringberg	1 214	315		
Kylemore	4 328	4 596		
Langebaan	8 297	411		
Langebaanweg	952	134		
Morreesburg *	7 760	285	110	42 (38.2%)
Paarl	112 045	1 734		
Paternoster	1 971	790		
Piketberg *	12 075	910	102	40 (39.2%)
Pniel *	6 264	5 046	100	41 (41.0%)
Porterville *	7 057	884	106	43 (40.6%)
Riebeek Kasteel *	1 144	179	121	48 (39.7%)
Riebeek Wes *	4 350	1 269	106	43 (40.6%)
Saldana	28 142	1 621		
Saron	7 843	3 688		
Tulbagh *	8 969	2 353	106	43 (40.6%)
Velddrif *	11 017	1 242	91	33 (36.3%)
Vredenburg	38 382	2 792		
Wellington	55 543	1 842		
Wittewater	848	1 775		
Wolseley *	1 528	650	100	36 (36.0%)



Supplementary Fig 3.1 Raw data for the regression analysis of Human Footprint (hf); Mean Annual Temperature (Bio1); Annual Precipitation (Bio12) relative to individual towns by 1) Total Town Species Richness; 2) Town species also noted within SAPIA.

Thesis Conclusions:

This thesis comprises three studies, each at a different scale, which set out to investigate the patterns and extent of spread of alien and invasive plant species, specifically in small towns in the same geographic region (see Fig. i. in the Introduction). My aim was to understand whether there was a way of quickly surveying small urban areas - to rapidly, but accurately, assess the full set of alien and invasive plant species present in a town. I was also interested to determine whether any patterns of distribution could be detected which could assist municipal managers in South Africa in their efforts to comply with national legislation and to control these problematic species in the urban areas under their jurisdiction. I considered it important to determine whether alien plant species within towns posed any risk to their surrounding environments, given the differences that exist between the human-manipulated microclimate and edaphic conditions inside towns and those in the surrounding landscape. Do plants that spread within towns also spread into the natural systems beyond the urban fringe?

To answer the questions around inventories, location, abundance and distribution of alien plants in small urban spaces, I investigated Riebeek Kasteel, a small town in the Berg River catchment in the Western Cape province of South Africa for my first chapter. I compiled an detailed inventory of all alien plant species observed during a survey where all public roads were treated as transects and data were collected every 10 m along each transect. Resultant species numbers were broken down into their occurrence and abundance by land-use type to establish distribution patterns. This required a substantial search effort and took considerable taxonomic expertise (my own and that of several taxonomists) to complete. I found that the vast majority of species diversity was located in gardens and on road-curbs, particularly those in the centres of towns. A large proportion of these species were also recorded as being either listed invasive species or were known from the literature to be 'weeds' in the region (DEA 2014; Henderson 2001; Bromilow 2010) and many of these problem plant species were found to be very abundant in the town. Because of the context-specific diversity within and between gardens, any short-cuts in survey methodology would lower the overall confidence level of results of all alien species, but their abundance throughout the town implies problem species should still be encountered.

In South Africa, municipalities (excluding large, metropolitan municipalities) consist of a number of urban centres within a matrix of agricultural and natural areas. Consequently the findings of this chapter, which suggest that there is a very high alien and invasive species plant load within small urban spaces, need to be taken into consideration especially in the context of NEM:BA compliance.

For Chapter 2, my aim was to apply a more rapid urban survey methodology than the on-foot approach of the previous chapter, and to use this method to survey an additional eleven small urban areas within the Berg River catchment. Chapter 1 found that reducing the number of gardens surveyed reduces the confidence in total alien plant species records, but it also found that the most abundant alien plants in the urban space tended to be invasive. So, whilst this chapter's truncated survey would undoubtedly not record the total alien species pool for surveyed towns, one would still be confident that a high proportion of the invasive plant species would be encountered and recorded using this methodology. I therefore developed and applied a vehicle-based search methodology using a selection of easily definable road types in small towns for the rapid assessment of the alien and invasive plant species found there. To determine which subset of the towns' alien plant component was less reliant on the specific conditions within town, and was thus able to naturalize in the surrounding areas, I cross-checked towns' species lists against a regional database of naturalization records (the South African Plant Invader Atlas; SAPIA). Analysing the results of this survey should assist municipal managers in designing their own approaches in their efforts to comply with NEM:BA.

Using this approach, I found a high proportion of invasive plant species within the pool of alien plants recorded for all towns surveyed (similarly to the results of Chapter 1 for a single town). There was a clear relationship between a town's ability to host alien and invasive alien plant species and the total road network length for that town. However, contrary to the prevailing view in the literature (e.g., Spear et al. 2013; Aronson et al. 2014a; Aronson et al. 2014b), I found no significant relationship between alien or invasive species number and urban population density or age of town. As in Chapter 1, it was noted that road types in the urban centre generally contained the bulk of both alien and invasive alien plant species for a given town. Main roads were an exception, as this category of road was generally associated with high levels of commercial activity (e.g., parking lots and shopping centres) which often precluded plants. Interestingly, low-income areas (a legacy of apartheid segregations laws) showed relatively high proportions of alien, and specifically, invasive alien plant species. This finding is contrary to other studies (Sharma et al. 2010; Santos et al. 2011), but could be an artefact of the depressed economic conditions and the high degree of disturbance in these areas. Species which are naturalized or invasive are often disturbance-tolerant species with a proven ability to survive in such conditions. They are thus both ideal choices for gardens in these areas, and able to capitalise on conditions here. This finding means that future alien plant surveys in urban areas should include low-income areas in their design.

The kinds of context-specific diversity observed between gardens in Chapter 1 were again apparent, which increased the heterogeneity within each town. Interestingly however, the total flora component across all towns in the region demonstrated very high homogeneity. The absence of formal horticultural trade like garden centres in most of the small towns surveyed here suggests that long-distance jump-dispersal (*sensu* Horvitz et al. 2017) is taking place between towns (i.e. gardeners trading propagules within the region) or between these small towns and larger urban centres in the area which have retail nurseries. It might also mean that towns have been historically constrained by the diversity of ornamental plants available through the trade (Smith et al. 2006). In light of the predicted future availability of new species through the internet trade (Lenda et al. 2014), one might predict a growing invasion debt with more species likely to naturalize out of this pool of horticulture in the future.

Chapter 3 used literature on the introduction of invasive plant species to urban centres and their subsequent spread to develop scenarios that explained the patterns of alien plant distribution in these areas. To investigate whether alien plants posed any risk to regional flora, I compared the alien plant species data from all the towns surveyed in Chapter 2 to records of invasive plants receiving management attention within the catchment. Plants in this subset were investigated for their reason for introduction. This identified which species were entering towns through the horticulture trade and were capable of 'jumping the garden fence'. These databases were compiled from Working for Water records (as well as from agencies implementing programs under this body, including early detection sources); CapeNature protected natural areas and the SAPIA list of naturalized plant species for the region. I found that nearly half of the most abundant alien plant species in towns were invasive in the region; the majority (65 %) had been introduced for horticulture. Many species that were recorded in towns and that are also listed in SAPIA are not currently noted by managers of invasive plant species in natural areas of this catchment. This set probably represents a "new wave of invasions in waiting", largely emanating from urban areas. Most of these are tall woody species - the same growth form as most of the invasive species that are currently being managed in the catchment (and the same growth form that causes widespread impacts in other parts of the world; Pyšek et al. 2009; Pyšek et al. 2011; Richardson and Rejmánek 2011). Seventy percent of those species being managed in the catchment are also recorded within towns, implying that re-invasions of these species from towns is likely unless these urban populations are effectively managed in conjunction with those populations in natural areas.

Results from this thesis show that studying alien plant species within urban settings requires a high degree of sampling effort as well as taxonomic expertise, which is not easily circumvented without compromising the confidence of results. This provides an additional challenge to the reported capacity constraints faced by small South African municipalities who must comply with national legislation relating to biological invasions. Gardens and horticulture account for the majority of alien plant species diversity encountered in the towns that were surveyed, particularly in the urban centres and the low-income areas. Despite the context-specificity of within-town heterogeneity of alien floras, all towns in the region had similar suites of alien and invasive species and are thus fairly homogenous in terms of their alien flora.

The results of this study also highlight the scale of the task facing municipal managers in their efforts to comply with legislation relating to invasive species management; but they should also be useful in guiding these managers in the design and execution of the surveys they will need to undertake to achieve this compliance. The results indicate that reasonably comprehensive lists of alien and invasive plant species can be achieved using vehicle-based road surveys in the centres of towns and their low-income sections (although this process will still require requiring high levels of taxonomic expertise). The most abundant species in these localities are likely to be those that are also invasive in the region (which can be confirmed by cross-referencing results with SAPIA records). This kind of information will be useful to municipal managers as it establishes which alien plant species in urban areas need to be prioritised for management in order to protect the surrounding natural environments; either from new invasions or from re-introduction of previously controlled species.

There are still gaps in our knowledge of alien and invasive plant species within small urban centres in South Africa and internationally. Further studies in this area will help in gaining a better understanding of these dynamic environments and will assist managers in prioritising and dealing with potentially invasive species within towns. Among the future research challenges that require attention in light of this study are the following:

- Municipalities in South Africa need to urgently asses their urban invasive species load, particularly in their small urban centres (as these are capable of launching new invasions and because they are more numerous in the landscape).
- Further research, similar to that reported in this thesis is needed in other catchments within South Africa (and internationally) to establish whether the trends reported here apply to other regions in the country (or globally).
- Research on the attitudes of gardeners in small urban centres to alien and potentially invasive plant species (*sensu* Shackleton and Shackleton, 2016) will be very enlightening, as these attitudes are potentially the largest drivers of selection of species in the first place.
- Similarly, studies to investigate NEM:BA compliance and attitudes of both the formal and informal horticultural trade needs to be undertaken on a national (and international) scale to better understand this pathway and potentially limit its future impact.

The worldwide predominance of the selection of alien over indigenous plants for ornamental horticulture means that many more species of garden subjects will become invasive over time. Plant invasions in urban areas are therefore very important to consider in conjunction with those in natural and semi-natural areas; particularly those of small towns given their number and proximity to natural areas. A dynamic exists where alien plant species in towns are likely to be undermining current clearing operations in adjacent areas through the continuous supply of propagules for re-invasion of these sites, as well as being the source of new invasions into the future.

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Appendices:

Appendix A: Full list of alien plant species recorded for the small South African town of Riebeek Kasteel where all public roads were surveyed at 10 m intervals in spring 2015. Abundances were recorded as stems of woody plants or 1 individual equivalent to every 1m^2 for creeping and spreading plants. Each species' category listing under the National Environmental Management: Biodiversity Act (NEM:BA) Regulations for the Western Cape province of South Africa is noted (DEA 2014).

Taxon	**Family**	**NEM:BA Category**	**Abundance**
***Acacia mearnsii* De Wild.**	Fabaceae	2	70
***Acacia melanoxylon* R.Br.**	Fabaceae	2	31
***Acacia podalyriifolia* G.Don**	Fabaceae	1b	29
***Acacia pycnantha* Benth.**	Fabaceae	1b	328
***Acacia saligna* (Labill.) Wendl.**	Fabaceae	1b	1211
***Acanthus mollis* L.**	Acanthaceae		10
***Acer negundo* L.**	Sapindaceae	3	93
***Acer palmatum* Thunb.**	Aceraceae/ Sapindaceae		2
***Acer* sp.**	Aceraceae/ Sapindaceae	3	3
***Aeonium arboreum* (L.) Webb & Berthel.**	Crassulaceae		15
Agave americana* L. subsp. *americana* var. *americana	Asparagaceae	3	603
***Agave americana* var. *mediopicta* Trel. 'Alba'**	Asparagaceae		4
***Agave attenuata* Salm-Dyck**	Asparagaceae		286
***Agave sisalana* Perrine**	Asparagaceae	2	464
***Ageratina adenophora* (Spreng.) R.M.King & H.Rob.**	Asteraceae	1b	10
***Ageratum conyzoides* L.**	Asteraceae	1b	1
***Ailanthus altissima* (Mill.) Swingle**	Simaroubaceae	1b	10
***Allium triquetrum* L.**	Alliaceae		10
***Alstroemeria* sp.**	Alstroemeriaceae		2
***Ammi majus* L. var. *glaucifolium* (L.) Godr.**	Apiaceae		4
***Amphilophium buccunatorium* (DC.) L.G.Lohmann**	Bignoniaceae		52
***Anredera cordifolia* (Ten.) Steenis**	Basellaceae	1b	67
***Araucaria heterophylla* (Salisb.) Franco**	Araucariaceae		22
***Arundo donax* L.**	Poaceae	1b	1159
***Atriplex* sp.**	Amaranthaceae/ Chenopodiaceae	1b/2	5
***Austrocylindropuntia cylindrica* (Juss. ex Lam.) Backeb.**	Cactaceae	1a	1
***Austrocylindropuntia subulata* (Muehlenpf.)**	Cactaceae	1b	8

Backeb. subsp. *exaltata* (A.Berger) D.R.Hunt			
***Avena fatua* L.**	Poaceae		9835
Bauhinia variegata* L. var. *variegata	Fabaceae	3	16
***Betula pendula* Roth**	Betulaceae		5
***Bidens pilosa* L.**	Asteraceae		20
***Bougainvillia* sp.**	Nyctaginaceae		718
***Brachychiton acerifolius* (A.Cunn.) F.Muell.**	Malvaceae		10
***Breynia disticha* J.R.Forst. & G.Forst.**	Euphorbiaceae		28
***Briza maxima* L.**	Poaceae		555
***Bromus* sp.**	Poaceae		37
***Brugmansia × candida* Pers.**	Solanaceae		9
***Brunfelsia pauciflora* (Cham. & Schltdl.) Benth.**	Solanaceae		14
***Bryophyllum delagoense* (Eckl. & Zeyh.) Schinz**	Crassulaceae	1b	2
***Bryophyllum fedtschenkoi* (Raym.-Hamet & Perr.) Lauz.-March.**	Crassulaceae		200
***Buddleja madagascariensis* Lam.**	Scrophulariaceae	3	2
***Caesalpinia ferrea* Tul.**	Fabaceae		72
***Callistemon* sp.**	Myrtaceae	3	170
***Camellia* sp.**	Theaceae		2
***Canna indica* L.**	Cannaceae	1b	236
***Carica papaya* L.**	Caricaceae		12
***Carya illinoinensis* (Wangenh.) K.Koch**	Juglandaceae		16
***Casuarina cunninghamiana* Miq.**	Casuarinaceae	2	579
***Catharanthus roseus* (L.) G.Don**	Apocynaceae	1b	444
***Celtis* sp.**	Ulmaceae	3	13
***Centranthus ruber* (L.) DC.**	Caprifoliaceae/ Valerianaceae	1b	72
***Cereus hildmannianus* K.Schum.**	Cactaceae	1b	8
***Cereus jamacaru* DC.**	Cactaceae	1b	178
***Cereus* sp.**	Cactaceae	1b	5
***Cestrum elegans* (Brongn.) Schltdl.**	Solanaceae	1b	5
***Cestrum laevigatum* Schltdl.**	Solanaceae	1b	10
***Chamelaucium uncinatum* Schauer**	Myrtaceae		4
***Chenopodium album* L.**	Chenopodiaceae		25
***Cinnamomum camphora* (L.) J.Presl**	Lauraceae	3	24
***Cirsium vulgare* (Savi) Ten.**	Asteraceae	1b	2
***Cistus parviflorus* Lam.**	Asteraceae		2
***Cistus x argenteus* Dans.**	Cistaceae		1
***Citharexylum spinosum* L.**	Verbenaceae		6
***Citrus limon* (L.) Burm.f.**	Rutaceae		53
***Citrus sinensis* (L.) Osbeck**	Rutaceae		1
***Cleistocactus* sp.**	Cactaceae		5
***Convolvulus* sp.**	Convolvulaceae		5

Coprosma repens **A.Rich.**	Rubiaceae		1
Cortaderia selloana **(Schult.) Asch. & Graebn.**	Poaceae	1b	1
Corymbia ficifolia **(F.Muell.) K.D.Hill & L.A.S.Johnson**	Myrtaceae		12
Cosmos **sp.**	Asteraceae		100
Cotoneaster **sp.**	Rosaceae	1b	14
Cotula turbinata **L.**	Asteraceae		693
Crotalaria agatiflora **Schweinf. subsp.** ***agatiflora***	Fabaceae	1b	4
Cupressus **sp.**	Cupressaceae		699
Cydonia oblonga **Mill.**	Rosaceae		5
Cylindropuntia fulgida **(Engelm.) F.M.Knuth var.** ***mamillata*** **(A.Schott ex Engelm.) Backeb.**	Cactaceae	1b	4
Cylindropuntia fulgida **(Engelm.) F.M.Knuth var.** ***mamillata*** **(A.Schott ex Engelm.) Backeb. forma** ***monstrosa***	Cactaceae	1b	2
Cynodon dactylon **(L.) Pers.**	Poaceae		130
Datura stramonium **L.**	Solanaceae	1b	65
Disocactus **sp.**	Cactaceae	0	1
Duranta erecta **L.**	Verbenaceae		797
Echeveria gibbiflora **DC.**	Crassulaceae		100
Echinocereus pentalophus **DC.**	Cactaceae		12
Echinopsis schickendantzii **F.A.C.Weber**	Cactaceae	1b	42
Echinopsis **sp.**	Cactaceae	1b	45
Echium plantagineum **L.**	Boraginaceae	1b	2358
Erigeron bonariensis **L.**	Asteraceae		20
Eriobotrya japonica **(Thunb.) Lindl.**	Rosaceae	1b	28
Erodium moschatum **(L.) L'Hér.**	Geraniaceae		797
Eucalyptus **sp.**	Myrtaceae	1b/2	865
Euphorbia pulcherrima **Willd. ex Klotzsch**	Euphorbiaceae		11
Ficus benjamina **L.**	Moraceae		32
Ficus carica **L.**	Moraceae		153
Ficus elastica **Roxb. ex Hornem.**	Moraceae		3
Ficus microcarpa **L. var.** ***microcarpa***	Moraceae		12
Ficus pumila **L.**	Moraceae		39
Foeniculum vulgare **Mill. var.** ***vulgare***	Apiaceae		210
Fraxinus angustifolia **Vahl**	Oleaceae		90
Fumaria muralis **Sond. ex W.D.J.Koch subsp.** ***muralis***	Fumariaceae		5
Fumaria **sp.**	Fumariaceae		64
Gaura lindheimeri **Engelm. & A.Gray**	Onagraceae		276
Gelsemium sempervirens **Aiton**	Gelsemiaceae		1
Genista monspessulana **(L.) L.A.S.Johnson**	Fabaceae	1a	5

Glebionis coronaria **(L.) Cass. ex Spach**	Asteraceae		30
Grevillea robusta **A.Cunn. ex R.Br.**	Proteaceae	3	121
Grey date palm	Arecaceae	3	2
Hakea salicifolia **(Vent.) B.L.Burtt**	Proteaceae	1b	302
Hedera helix **L. var. *helix***	Araliaceae	3	164
Hedychium coronarium **J.König**	Zingiberaceae	3	15
Helichrysum **sp.**	Compositae		2
Hesperoyucca whipplei **(Torr.) Trel**	Asparagaceae		1
Hibiscus **sp.**	Malvaceae		214
Homalanthus populifolius **Graham**	Euphorbiaceae	1b	3
Hydrangea macrophylla **(Thunb.) Ser.**	Hydrangeaceae		2
Hylocereus undatus **(Haw.) Britton & Rose**	Cactaceae	2	2
Hypochaeris radicata **L.**	Asteraceae		148
Ilex aquifolium **L.**	Aquifoliaceae		3
Ipomoea cairica **(L.) Sweet var. *cairica***	Convolvulaceae		84
Ipomoea purpurea **(L.) Roth**	Convolvulaceae	3	105
Ipomoea **sp.**	Convolvulaceae	1b/3	22
Jacaranda mimosifolia **D.Don**	Bignoniaceae		93
Jasminum officinale **L.**	Oleaceae		28
Lactuca **sp.**	Asteraceae		4
Lagerstroemia indica **L.**	Lythraceae		67
Lagunaria patersonia **(Andrews) G.Don**	Malvaceae		3
Lagurus ovatus **L.**	Poaceae		9
Lantana camara **L.**	Verbenaceae	1b	106
Laurus nobilis **L.**	Lauraceae		19
Lavandula **sp.**	Lamiaceae		247
Lemna gibba **L.**	Lemnaceae		5
Ligustrum japonicum **Thunb.**	Oleaceae	1b	6
Ligustrum lucidum **W.T.Aiton**	Oleaceae	1b	42
Ligustrum sinense **Lour.**	Oleaceae	1b	8
Limonium perezii **(Stapf) F.T.Hubb.**	Plumbaginaceae		67
Liquidambar styraciflua **L.**	Hamamelidaceae (Altingiaceae)		12
Lolium **sp.**	Poaceae		44
Lonicera japonica **Thunb. var. *japonica***	Caprifoliaceae	3	36
Lupinus **sp.**	Fabaceae		60
Lycianthes rantonnetii **(Carrière ex Lesc.) Bitter**	Solanaceae		121
Lytocaryum weddellianum **(H.Wendl.) Toledo**	Arecaceae		6
Macadamia **sp.**	Proteaceae		1
Magnolia grandiflora **L.**	Magnoliaceae		3
Malus domestica **Borkh.**	Rosaceae		1
Malva arborea **(L.) Webb & Berthel.**	Malvaceae		13
Malva parviflora **L. var. *parviflora***	Malvaceae		126

***Mammillaria* sp.**	Cactaceae		30
***Medicago sativa* L.**	Fabaceae		172
Melaleuca armillaris* (Sol. ex Gaertn.) Sm. subsp. *armillaris	Myrtaceae		1
Melaleuca bracteata* F.Muell. var. *revolution gold	Myrtaceae		45
***Melia azedarach* L.**	Meliaceae	1b	575
***Metrosideros excelsa* Sol. ex Gaertn.**	Myrtaceae		6
***Monstera deliciosa* Liebm.**	Araceae		54
Morus alba* L. var. *alba	Moraceae	3	67
***Myoporum tenuifolium* G.Forst.**	Myoporaceae	3	323
Myrtus communis* L. var. *communis	Myrtaceae		2
***Nandina domestica* Thunb.**	Berberidaceae		24
Nephrolepis cordifolia* (L.) C.Presl var. *cordifolia	Nephrolepidaceae	1b	107
***Nerium oleander* L.**	Apocynaceae	1b	109
***Nothoscordum gracile* (Aiton) Stearn**	Amaryllidaceae		50
***Olea europaea* L.**	Oleaceae		937
***Opuntia elata* Link & Otto**	Cactaceae	1b	28
***Opuntia ficus-indica* (L.) Mill.**	Cactaceae	1b	116
***Opuntia microdasys* (Lehm.) Pfeiff.**	Cactaceae	1b	19
***Opuntia monacantha* Haw.**	Cactaceae	1b	9
***Opuntia* sp.**	Cactaceae	1a/1b	1
Opuntia stricta* (Haw.) Haw. var. *stricta	Cactaceae	1b	12
***Orobanche* sp.**	Orobanchaceae	1b	3
***Papaver* sp.**	Papaveraceae		211
***Parkinsonia aculeata* L.**	Fabaceae	1b	1
***Parthenocissus quinquefolia* (L.) Planch.**	Vitaceae		24
***Parthenocissus tricuspidata* Planch.**	Vitaceae		62
***Passiflora edulis* Sims**	Passifloraceae		41
***Pennisetum clandestinum* Hochst. ex Chiov.**	Poaceae	1b	5292
***Pennisetum setaceum* (Forssk.) Chiov.**	Poaceae	1b	218
Persea americana* Mill. var. *americana	Lauraceae		11
***Persicaria capitata* (Buch.-Ham. ex D.Don) H.Gross**	Polygonaceae	1b	1
***Persicaria lapathifolia* (L.) Gray**	Polygonaceae		65
***Persicaria* sp.**	Polygonaceae		2
***Phoenix canariensis* Chabaud**	Arecaceae		195
***Phoenix roebelenii* O'Brien**	Arecaceae		50
***Phormium tenax* J.R.Forst. & G.Forst.**	Asphodelaceae/ Hemerocallidaceae		2
***Phyllostachys* sp.**	Poaceae		113
***Physalis peruviana* L.**	Solanaceae		5
***Phytolacca dioica* L.**	Phytolaccaceae	3	6
***Phytolacca octandra* L.**	Phytolaccaceae	1b	11

***Pinus* sp.**	Pinaceae	1b/2	22
***Pittosporum undulatum* Vent.**	Pittosporaceae	1b	69
***Plantago lanceolata* L.**	Plantaginaceae		85
***Platanus acerifolia* (Aiton) Willd.**	Platanaceae		33
***Plectranthus barbatus* Andrews var. *grandis* (L.H.Cramer) Lukhoba & A.J.Paton**	Lamiaceae	1b	47
Plectranthus ornatus Codd	Lamiaceae		21
***Plumeria* sp.**	Apocynaceae		35
***Podranea ricasoliana* (Tanfani) Sprague**	Bignoniaceae		40
Pontederia cordata* L. var. *cordata	Pontederiaceae	1b	15
***Populus canescens* (Aiton) Sm.**	Salicaceae	2	268
***Populus deltoides* Bartram ex Marshall**	Salicaceae		11
***Populus nigra* L. var. *italica* Münchh.**	Salicaceae		274
***Populus simonii* Carrière**	Salicaceae		111
***Prosopis* sp.**	Fabaceae		5
***Prunus domestica* L.**	Rosaceae		16
Prunus persica* (L.) Batsch var. *persica	Rosaceae		82
***Prunus serrulata* Lindl.**	Rosaceae		3
***Prunus* sp.**	Rosaceae	1b	1
***Psidium cattleianum* Sabine**	Myrtaceae	1b	2
***Psidium guajava* L.**	Myrtaceae		65
***Punica granatum* L.**	Lythraceae		37
***Pyracantha* sp.**	Rosaceae		112
***Pyrus* sp.**	Rosaceae		3
***Quercus nigra* L.**	Fagaceae		37
***Quercus palustris* L.**	Fagaceae		36
***Quercus palustris* L.**	Fagaceae		1
***Quercus petraea* L. ex Liebl.**	Fagaceae		22
***Quercus robur* L.**	Fagaceae		276
***Quercus suber* L.**	Fagaceae		4
***Raphanus raphanistrum* L.**	Brassicaceae		515
***Rhaphiolepis indica* (L.) Lindl.**	Rosaceae		32
Ricinus communis* L. var. *communis	Euphorbiaceae	2	350
***Robinia pseudoacacia* L.**	Fabaceae	1b	1
***Rosa* sp.**	Rosaceae		1076
***Rosmarinus officinalis* L.**	Lamiaceae		76
***Rubus* sp.**	Rosaceae	1b/2	1
***Rumex* sp.**	Polygonaceae	1b	23
***Ruscus* sp.**	Asparagaceae		3
Salix babylonica* L. var. *babylonica	Salicaceae		21
***Salix* sp.**	Salicaceae		8
***Salsola kali* L.**	Amaranthaceae/ Chenopodiaceae	1b	10
***Salvia leucantha* Cav.**	Lamiaceae		1
***Salvinia molesta* D.S.Mitch.**	Salviniaceae	1b	5

Sambucus nigra **L. var.** ***nigra***	Caprifoliaceae	1b	40
Sansevieria trifasciata **Prain**	Asparagaceae		18
Schefflera actinophylla **(Endl.) Harms**	Araliaceae	1b	4
Schinus molle **L.**	Anacardiaceae		53
Schinus terebinthifolius **Raddi**	Anacardiaceae	3	470
Schizolobium parahyba **(Vell.) Blake**	Fabaceae		3
Senna didymobotrya **(Fresen.) H.S.Irwin & Barneby**	Fabaceae	1b	20
Sesbania punicea **(Cav.) Benth.**	Fabaceae	1b	165
Sida rhombifolia **L.**	Malvaceae		178
Solanum jasminoides **J. Paxton**	Solanaceae		3
Solanum mauritianum **Scop.**	Solanaceae	1b	1
Solanum nigrum **L.**	Solanaceae		137
Sonchus **sp.**	Asteraceae		18
Spartium junceum **L.**	Fabaceae	1b	1
Stellaria media **(L.) Vill.**	Caryophyllaceae		6
Syagrus romanzoffiana **(Cham.) Glassman**	Arecaceae		238
Syngonium podophyllum **Schott**	Araceae		8
Syzygium paniculatum **Gaertn.**	Myrtaceae		1095
Tamarix **sp.**	Tamaricaceae	1b	5
Taxodium distichum **(L.) Rich.**	Cupressaceae		5
Tecoma stans **(L.) Juss. ex Kunth**	Bignoniaceae	1b	44
Tipuana tipu **(Benth.) Kuntze**	Fabaceae	3	60
Trachelospermum jasminoides **Lem.**	Apocynaceae		25
Tradescantia fluminensis **Vell.**	Commelinaceae	1b	7
Tradescantia pallida **(Rose) D.R.Hunt**	Commelinaceae		2
Tradescantia zebrina **Bosse**	Commelinaceae	1b	2
Tribulus terrestris **L.**	Zygophyllaceae		99
Trifolium angustifolium **L. var.** ***angustifolium***	Fabaceae		274
Tropaeolum majus **L.**	Tropaeolaceae		354
Ulmus parvifolia **Jacq.**	Ulmaceae		8
Unidentified 1	Unknown		1
Unidentified 2	Unknown		1
Unidentified 3	Unknown		40
Unidentified 4	Unknown		1
Unidentified 5	Cactaceae		3
Unidentified 6	Unknown		1
Unidentified 7	Unknown		1
Unidentified 8	Unknown		1
Unidentified 9	Unknown		2
Unidentified 10	Cactaceae		22
Unidentified 11	Unknown		1
Unidentified 12	Unknown		1
Unidentified 13	Unknown		1

Unidentified 14	Unknown		17
Unidentified 16	Unknown		4
Unidentified 17	Unknown		1
Unidentified 18	Myrtaceae		2
Unidentified 19	Fabaceae		1
Unidentified 20	Myrtaceae		1
Unidentified Oak 2	Fagaceae		1
Unidentified Oak 3	Fagaceae		2
Unidentified Oak 4	Fagaceae		4
***Urtica urens* L.**	Urticaceae		104
***Verbascum virgatum* Stokes**	Scrophulariaceae		2
***Verbena bonariensis* L.**	Verbenaceae	1b	1
***Viburnum odoratissimum* Ker Gawl.**	Viburnaceae		47
***Viburnum tinus* L.**	Viburnaceae		1
***Vicia benghalensis* L.**	Fabaceae		402
Vicia sativa* L. subsp. *sativa	Fabaceae		355
***Vinca major* L.**	Apocynaceae	1b	136
***Vitis vinifera* L.**	Vitaceae		86819
Washingtonia robusta	Arecaceae		306
***Westringia fruticosa* (Willd.) Druce**	Lamiaceae		2
***Westringia* sp.**	Lamiaceae		2
***Wisteria floribunda* (Willd.) DC.**	Fabaceae		110
***Xanthium strumarium* L.**	Asteraceae	1b	97
***Yucca aloifolia* L.**	Asparagaceae		5
Yucca gloriosa* L. var. *gloriosa	Asparagaceae		141
***Yucca* sp.**	Asparagaceae		20

Appendix B. Complete alien species list for the Berg River Catchment, South Africa when all data sets are combined. Species are listed alphabetically. Their family group is indicated and their presence in the SAPIA, CapeNature, Working for Water and Town-survey data sets is indicated with a “1” in the relevant column. The invasive status of each species in South Africa is indicated by the category under which it is listed. South African legislation, the National Environmental: Biodiversity Act (NEM:BA; Act #10 of 2004), assigns one of four categories to declared invader species: (i) Category 1a species are the focus of eradication targets, (ii) Category 1b species may not be traded, must form part of a management plan focussed on their control, and they must be removed where possible, (iii) Category 2 species can only be grown under permit, and (iv) Category 3 species are allowed to remain where found, but may not be propagated or traded. Where a genus containing several listed species is shown, all possible NEM:BA categories for species within this genus are indicated. Some species have different NEMBA category designations depending on their location within the country, so we show only their relevant listing for the Western Cape province of South Africa.

Species	Family	NEMBA Category	SAPIA	CapeNature	Working for water	Towns surveys
Abelia sp.	Caprifoliaceae (Linnaeaceae)		0	0	0	1
Abutilon pictum* (Gillies ex Hook. & Arn.) Walp. var. *pictum	Malvaceae		0	0	0	1
***Acacia adunca* A.Cunn. ex G.Don**	Fabaceae	1a	1	0	0	0
***Acacia baileyana* F.Muell.**	Fabaceae	3	1	1	1	1
***Acacia cultriformis* A.Cunn. ex G.Don**	Fabaceae		1	0	0	0
***Acacia cyclops* A.Cunn. ex G.Don**	Fabaceae	1b	1	1	1	1
***Acacia dealbata* Link**	Fabaceae	2	0	0	1	0
***Acacia elata* A.Cunn. ex Benth.**	Fabaceae	1b	1	0	1	1
***Acacia galpinii* Burtt Davy**	Fabaceae		0	0	0	1
***Acacia implexa* Benth.**	Fabaceae	1a	1	0	0	0
***Acacia longifolia* (Andrews) Willd.**	Fabaceae	1b	1	1	1	1
***Acacia mearnsii* De Wild.**	Fabaceae	2	1	1	1	1
***Acacia melanoxylon* R.Br.**	Fabaceae	2	1	1	1	1
***Acacia paradoxa* DC.**	Fabaceae	1a	1	0	0	0
***Acacia podalyriifolia* G.Don**	Fabaceae	1b	1	0	0	1

***Acacia pycnantha* Benth.**	Fabaceae	1b	1	1	1	1
***Acacia saligna* (Labill.) H.L.Wendl.**	Fabaceae	1b	1	1	1	1
Acacia sp.	Fabaceae		0	0	1	1
***Acalypha welwitschianus* Müll.Arg.**	Euphorbiaceae		0	0	0	1
***Acanthus mollis* L.**	Acanthaceae		0	0	0	1
***Acer negundo* L.**	Aceraceae	3	1	0	0	1
***Acer palmatum* Thunb.**	Aceraceae		0	0	0	1
Acer sp.	Aceraceae	3	0	0	0	1
Aechmea spp.	Bromeliaceae		0	0	0	1
***Aeonium arboreum* (L.) Webb & Berthel.**	Crassulaceae		0	0	0	1
Agave americana* L. subsp. *americana* var. *americana	Asparagaceae		1	0	0	1
***Agave attenuata* Salm-Dyck**	Asparagaceae		0	0	0	1
***Agave sisalana* Perrine**	Asparagaceae	2	0	0	0	1
Agave sp.	Asparagaceae		1	0	0	1
***Ageratina adenophora* (Spreng.) R.M.King & H.Rob.**	Asteraceae	1b	1	0	0	1
***Ageratum conyzoides* L.**	Asteraceae	1b	0	0	0	1
***Ailanthus altissima* (Mill.) Swingle**	Simaroubaceae	1b	1	0	0	1
***Allium triquetrum* L.**	Amaryllidaceae		0	0	0	1
***Alnus glutinosa* (L.) Gaertn.**	Betulaceae		0	0	1	1
Alstroemeria sp.	Alstroemeriaceae		0	0	0	1
***Ammi majus* L. var. *glaucifolium* (L.) Godr.**	Apiaceae		0	0	0	1
***Amphilophium buccunatorium* (DC.) L.G.Lohmann**	Bignoniaceae		0	0	0	1
***Anredera cordifolia* (Ten.) Steenis**	Basellaceae	1b	1	0	0	1
***Antigonon leptopus* Hook. & Arn.**	Polygonaceae	1b	1	0	0	0
***Apium graveolens* L.**	Apiaceae		1	0	0	0
***Araucaria heterophylla* (Salisb.) Franco**	Araucariaceae		0	0	0	1
***Araujia sericifera* Brot.**	Asclepiadaceae	1b	1	0	0	1

Arctotheca calendula **(L.) Levyns**	Asteraceae		0	0	0	1
Argemone albiflora **Hornem. subsp.** ***texana*** **G.B.Ownbey**	Papaveraceae		1	0	0	0
Argemone ochroleuca **Sweet subsp.** ***ochroleuca***	Papaveraceae	1b	1	0	0	0
Arum italicum **Mill.**	Araceae		0	0	0	1
Arundo donax **L.**	Poaceae	1b	1	0	1	1
Atriplex lindleyi **Moq. subsp.** ***inflata*** **(F.Muell.) Paul G.Wilson**	Chenopodiaceae		1	0	0	0
Atriplex muelleri **Benth.**	Chenopodiaceae		1	0	0	0
Atriplex nummularia **Lindl. subsp.** ***nummularia***	Chenopodiaceae	2	0	0	0	1
Atriplex sp.	Chenopodiaceae	1b/2	1	0	0	1
Austrocylindropuntia cylindrica **(Juss. ex Lam.) Backeb.**	Cactaceae	1a	0	0	0	1
Austrocylindropuntia subulata **(Muehlenpf.) Backeb. subsp. exaltata (A.Berger) D.R.Hunt**	Cactaceae	1b	0	0	0	1
Avena sp.	Poaceae		1	0	0	1
Azolla filiculoides **Lam.**	Azollaceae	1b	1	0	0	0
Bambusa balcooa **Roxb. ex Roxb.**	Poaceae		1	0	0	1
Bauhinia variegata **L. var.** ***variegata***	Fabaceae	3	1	0	0	1
Beaucarnea recurvata **Lem.**	Asparagaceae		0	0	0	1
Betula pendula **Roth**	Betulaceae		0	0	0	1
Bidens pilosa **L.**	Asteraceae		1	0	0	1
Blackiella inflata **(F.Muell.) Aellen**	Amaranthaceae		1	0	0	0
Boerhavia erecta **L.**	Nyctaginaceae		1	0	0	0
Bougainvillea sp.	Nyctaginaceae		1	0	0	1
Brachychiton acerifolius **(A.Cunn.) F.Muell.**	Malvaceae		0	0	0	1
Brachychiton	Malvaceae		0	0	0	1

populneus **(Schott & Endl.) R.Br.**						
Breynia disticha **J.R.Forst. & G.Forst.**	Phyllanthaceae		0	0	0	1
Briza maxima **L.**	Poaceae		1	0	0	1
Bromus catharticus **Vahl**	Poaceae		1	0	0	0
Bromus diandrus **Roth**	Poaceae		1	0	0	0
Bromus japonicus **Thunb.**	Poaceae		1	0	0	0
Bromus pectinatus **Thunb.**	Poaceae		1	0	0	0
Bromus sp.	Poaceae		1	0	0	1
Bromus willdenowii **Kunth**	Poaceae		1	0	0	0
Brugmansia × candida **Pers.**	Solanaceae		0	0	0	1
Brunfelsia pauciflora **(Cham. & Schltdl.) Benth.**	Solanaceae		0	0	0	1
Bryophyllum delagoense **(Eckl. & Zeyh.) Schinz**	Crassulaceae	1b	0	0	0	1
Bryophyllum fedtschenkoi **(Raym.-Hamet & Perr.) Lauz.-March.**	Crassulaceae		0	0	0	1
Buddleja madagascariensis **Lam.**	Buddlejaceae	3	0	0	0	1
Caesalpinia ferrea **Tul.**	Fabaceae		0	0	0	1
Callistemon sp.	Myrtaceae	3	1	0	0	1
Camellia sp.	Theaceae		0	0	0	1
Canna indica **L.**	Cannaceae	1b	1	0	0	1
Cardiospermum grandiflorum **Sw.**	Sapindaceae	1b	1	0	0	0
Carduus tenuiflorus **Curtis**	Asteraceae		1	0	0	0
Carica papaya **L.**	Caricaceae		0	0	0	1
Carissa macrocarpa **(Eckl.) A.DC.**	Apocynaceae		0	0	0	1
Carya illinoinensis **(Wangenh.) K.Koch**	Juglandaceae		0	0	0	1
Cascabela thevetia **(L.) Lippold**	Apocynaceae		0	0	0	1
Castanea sativa **Mill.**	Fagaceae		0	0	0	1

***Casuarina cunninghamiana* Miq.**	Casuarinaceae	2	1	1	0	1
***Casuarina equisetifolia* L.**	Casuarinaceae	2	1	0	0	0
Casuarina sp.	Casuarinaceae	2	1	0	0	1
***Catharanthus roseus* (L.) G.Don**	Apocynaceae	1b	1	0	0	1
Celtis sp.	Celtidaceae	3	0	0	0	1
***Centaurea cineraria* L.**	Asteraceae		0	0	0	1
***Centranthus ruber* (L.) DC.**	Caprifoliaceae	1b	1	0	0	1
***Cereus hildmannianus* K.Schum.**	Cactaceae	1b	0	0	0	1
***Cereus jamacaru* DC.**	Cactaceae	1b	0	0	0	1
***Cestrum elegans* (Brongn.) Schltdl.**	Solanaceae	1b	0	0	0	1
***Cestrum laevigatum* Schltdl.**	Solanaceae	1b	0	0	1	1
Cestrum sp.	Solanaceae	1b	0	0	1	0
***Chamelaucium uncinatum* Schauer**	Myrtaceae		0	0	0	1
***Chenopodium album* L.**	Chenopodiaceae		1	0	0	1
***Cinnamomum camphora* (L.) J.Presl**	Lauraceae	3	1	0	0	1
***Cirsium arvense* (L.) Scop.**	Asteraceae		1	0	0	0
***Cirsium vulgare* (Savi) Ten.**	Asteraceae	1b	1	0	0	1
Cistus x	Cistaceae		0	0	0	1
***Cistus parviflorus* Lam.**	Cistaceae		0	0	0	1
***Citharexylum spinosum* L.**	Verbenaceae		0	0	0	1
***Citrus limon* (L.) Burm.f.**	Rutaceae		0	0	0	1
Citrus sp.	Rutaceae		0	0	0	1
Citrus x	Rutaceae		0	0	0	1
Cleistocactus sp.	Cactaceae		0	0	0	1
***Coleonema pulchellum* I.Williams**	Rutaceae		0	0	0	1
***Colocasia esculenta* (L.) Schott**	Araceae		1	0	0	1
***Commelina benghalensis* L.**	Commelinaceae		1	0	0	0
***Convolvulus mauritanicus* L.**	Convolvulaceae		0	0	0	1
***Conyza bonariensis* (L.)**	Asteraceae		1	0	0	0

Cronquist						
***Conyza canadensis* (L.) Cronquist**	Asteraceae		1	0	0	0
***Coprosma repens* A.Rich.**	Rubiaceae		0	0	0	1
Coprosma sp.	Rubiaceae		0	0	0	1
***Cortaderia selloana* (Schult. & Schult.f.) Asch. & Graebn.**	Poaceae	1a	1	0	1	1
Cortaderia sp.	Poaceae	1a/1b	0	0	1	0
***Corymbia ficifolia* (F.Muell.) K.D.Hill & L.A.S.Johnson**	Myrtaceae		0	0	0	1
Cosmos sp.	Asteraceae		0	0	0	1
***Cotoneaster pannosus* Franch.**	Rosaceae	1b	1	0	0	1
***Cotoneaster vilmorinianus* G.Klotz**	Rosaceae		0	0	0	1
***Cotula turbinata* L.**	Asteraceae		0	0	0	1
***Crassula tetragona* L.**	Crassulaceae		0	0	0	1
***Crotalaria agatiflora* Schweinf.**	Fabaceae	1b	0	0	0	1
Cupressus sp.	Cupressaceae		1	0	0	1
***Cuscuta campestris* Yunck.**	Convolvulaceae	1b	1	0	0	0
***Cydonia oblonga* Mill.**	Rosaceae		1	0	0	1
***Cylindropuntia fulgida* (Engelm.) F.M.Knuth**	Cactaceae	1b	0	0	0	1
***Cylindropuntia imbricata* (Haw.) F.M.Knuth**	Cactaceae	1b	0	0	0	1
***Cynodon dactylon* (L.) Pers.**	Poaceae		1	0	0	1
***Cytisus scoparius* (L.) Link**	Fabaceae	1a	1	0	0	0
Datura sp.	Solanaceae	1b	0	0	0	1
***Datura stramonium* L.**	Solanaceae	1b	1	0	0	1
Disocactus sp.	Cactaceae		0	0	0	1
***Dittrichia graveolens* (L.) Greuter**	Asteraceae		1	0	0	0
***Dolichandra unguis-cati* (L.) L.G.Lohmann**	Bignoniaceae	1b	1	0	0	0
***Duranta erecta* L.**	Verbenaceae		0	0	0	1
***Echeveria gibbiflora* DC.**	Crassulaceae		0	0	0	1
Echinocactus grusonii	Cactaceae		0	0	0	1

Hildm.						
***Echinocereus pentalophus* (DC.) Lem.**	Cactaceae		0	0	0	1
***Echinopsis schickendantzii* F.A.C.Weber**	Cactaceae	1b	0	0	0	1
Echinopsis sp.	Cactaceae	1b	0	0	0	1
***Echium fastuosum* Aiton**	Boraginaceae		0	0	0	1
***Echium plantagineum* L.**	Boraginaceae	1b	1	0	0	1
***Echium violaceum* L.**	Boraginaceae		1	0	0	0
***Echium vulgare* L.**	Boraginaceae	1b	1	0	0	0
***Eichhornia crassipes* (Mart.) Solms**	Pontederiaceae	1b	1	0	0	0
***Elytrigia repens* (L.) Nevski**	Poaceae		1	0	0	1
***Erigeron bonariensis* L.**	Asteraceae		0	0	0	1
***Eriobotrya japonica* (Thunb.) Lindl.**	Rosaceae	1b	1	0	0	1
***Erodium moschatum* (L.) L'Hér.**	Geraniaceae		0	0	0	1
Eschscholzia californica* Cham. subsp. *californica	Papaveraceae		0	0	0	1
Eucalyptus sp.	Myrtaceae	1b/2	1	1	1	1
***Eugenia uniflora* L.**	Myrtaceae	1b	1	0	0	0
***Euphorbia caerulescens* Haw.**	Euphorbiaceae		0	0	0	1
***Euphorbia peplus* L.**	Euphorbiaceae		1	0	0	0
***Euphorbia pulcherrima* Willd. ex Klotzsch**	Euphorbiaceae		0	0	0	1
Ficus benjamina* L. var. *benjamina	Moraceae		0	0	0	1
***Ficus carica* L.**	Moraceae		1	0	0	1
***Ficus elastica* Roxb. ex Hornem.**	Moraceae		0	0	0	1
***Ficus macrophylla* Desf. ex Pers.**	Moraceae		0	0	0	1
Ficus microcarpa* L. var. *microcarpa	Moraceae		0	0	0	1
***Ficus pumila* L.**	Moraceae		0	0	0	1
***Ficus rubiginosa* Desf. ex Vent.**	Moraceae		0	0	0	1
Foeniculum vulgare	Apiaceae		0	0	0	1

Mill. var. vulgare						
***Fraxinus angustifolia* Vahl**	Oleaceae	3	1	0	0	1
Fuchsia sp.	Onagraceae		0	0	0	1
Fumaria sp.	Fumariaceae		0	0	0	1
***Furcraea foetida* (L.) Haw.**	Asparagaceae	1a	0	0	0	1
***Gaura lindheimeri* Engelm. & A.Gray**	Onagraceae		0	0	0	1
***Gelsemium sempervirens* Aiton**	Gelsemiaceae		0	0	0	1
***Genista monspessulana* (L.) L.A.S.Johnson**	Fabaceae	1a	0	0	0	1
***Glebionis coronaria* (L.) Cass. ex Spach**	Asteraceae		1	0	0	1
***Gleditsia triacanthos* L.**	Fabaceae	1b	1	0	0	1
***Gnidia squarrosa* (L.) Druce**	Thymelaeaceae		0	0	0	1
Gomphocarpus fruticosus* (L.) Aiton f. subsp. *fruticosus	Asclepiadaceae		0	0	0	1
***Gomphrena celosioides* Mart.**	Amaranthaceae		1	0	0	0
***Grevillea robusta* A.Cunn. ex R.Br.**	Proteaceae	3	1	0	1	1
***Grevillea rosmarinifolia* A.Cunn.**	Proteaceae	3	1	0	0	0
Guilleminea densa (Willd. ex Roem. & Schult.) Moq.	Amaranthaceae		1	0	0	0
***Hakea drupacea* (C.F.Gaertn.) Roem. & Schult.**	Proteaceae	1b	1	0	1	0
***Hakea gibbosa* (Sm.) Cav.**	Proteaceae	1b	1	1	0	0
***Hakea salicifolia* (Vent.) B.L.Burtt**	Proteaceae	1b	1	0	0	1
***Hakea sericea* Schrad. & J.C.Wendl.**	Proteaceae	1b	0	1	1	0
***Hakea suaveolens* R.Br.**	Proteaceae		1	0	0	0
Hedera helix* L. *var. helix	Araliaceae	3	0	0	0	1
Hedychium sp.	Zingiberaceae	1b	1	0	0	1
***Helianthus annuus* L.**	Asteraceae		1	0	0	1

***Hesperoyucca whipplei* (Torr.) Trel.**	Asparagaceae		0	0	0	1
Hibiscus sp.	Malvaceae		0	0	0	1
***Homalanthus populifolius* Graham**	Euphorbiaceae	1b	0	0	0	1
Hordeum sp.	Poaceae		1	0	0	0
***Hydrangea macrophylla* (Thunb.) Ser.**	Hydrangeaceae		0	0	0	1
***Hylocereus undatus* (Haw.) Britton & Rose**	Cactaceae	2	0	0	0	1
***Hymenosporum flavum* (Hook.) R.Br. ex F.Muell.**	Pittosporaceae		0	0	0	1
***Hypericum perforatum* L.**	Hypericaceae	2	1	0	0	0
***Hypochaeris radicata* L.**	Asteraceae		0	0	0	1
***Ilex aquifolium* L.**	Aquifoliaceae		0	0	0	1
***Inula graveolens* (L.) Desf.**	Asteraceae		1	0	0	0
Ipomoea cairica* (L.) Sweet var. *cairica	Convolvulaceae		1	0	0	1
***Ipomoea indica* (Burm.f.) Merr.**	Convolvulaceae	3	1	0	0	0
***Ipomoea purpurea* (L.) Roth**	Convolvulaceae	3	1	0	0	0
Ipomoea sp.	Convolvulaceae	1b/3	1	0	0	1
***Jacaranda mimosifolia* D.Don**	Bignoniaceae		1	0	0	1
***Jasminum humile* L.**	Oleaceae		0	0	0	1
***Jasminum mesnyi* Hance**	Oleaceae		0	0	0	1
***Jasminum officinale* L.**	Oleaceae		0	0	0	1
Juniperus sp.	Cupressaceae		1	0	0	0
***Kalanchoe beharensis* Drake**	Crassulaceae		0	0	0	1
***Koelreuteria paniculata* Laxm.**	Sapindaceae		1	0	0	0
***Lactuca serriola* L.**	Asteraceae		1	0	0	1
***Lagerstroemia indica* L.**	Lythraceae		0	0	0	1
***Lagunaria patersonia* (Andrews) G.Don**	Malvaceae		0	0	0	1
***Lagurus ovatus* L.**	Poaceae		0	0	0	1
***Lantana camara* L.**	Verbenaceae	1b	1	1	1	1

Lantana montevidensis **(Spreng.) Briq.**	Verbenaceae		0	0	0	1
Laurus nobilis **L.**	Lauraceae		0	0	0	1
Lavandula sp.	Lamiaceae		0	0	0	1
Lavatera arborea **L.**	Malvaceae		1	0	0	1
Lemna gibba **L.**	Lemnaceae		0	0	0	1
Lepidium bonariense **L.**	Brassicaceae		1	0	0	0
Leptospermum laevigatum **(Gaertn.) F.Muell.**	Myrtaceae	1b	1	1	1	0
Leucaena leucocephala **(Lam.) de Wit subsp.** ***leucocephala***	Fabaceae	2	0	0	0	1
Ligustrum japonicum **Thunb.**	Oleaceae	1b	0	0	0	1
Ligustrum lucidum **W.T.Aiton**	Oleaceae	1b	0	0	0	1
Ligustrum sinense **Lour.**	Oleaceae	1b	0	0	0	1
Limonium perezii **(Stapf) F.T.Hubb.**	Plumbaginaceae		0	0	0	1
Limonium sinuatum **(L.) Mill. subsp.** ***sinuatum***	Plumbaginaceae	1b	1	0	0	1
Liquidambar styraciflua **L.**	Hamamelidaceae (Altingiaceae)		0	0	0	1
Lonicera japonica **Thunb. var.** ***japonica***	Caprifoliaceae	3	1	0	0	1
Lonicera periclymenum **L.**	Caprifoliaceae		0	0	0	1
Lupinus albus **L.**	Fabaceae		0	0	0	1
Lycianthes rantonnetii **(Carrière ex Lesc.)** ***Bitter***	Solanaceae		0	0	0	1
Lytocaryum weddellianum **(H.Wendl.) Toledo**	Arecaceae		0	0	0	1
Macadamia sp.	Proteaceae		0	0	0	1
Magnolia acuminata **L.**	Magnoliaceae		0	0	0	1
Magnolia grandiflora **L.**	Magnoliaceae		0	0	0	1
Magnolia sp.	Magnoliaceae		0	0	0	1
Malus sp.	Rosaceae		1	0	0	1
Malva arborea **(L.)**	Malvaceae		1	0	0	1

Webb & Berthel.						
Malva parviflora* L. var. *parviflora	Malvaceae		0	0	0	1
Mammillaria sp.	Cactaceae		0	0	0	1
***Mangifera indica* L.**	Anacardiaceae		0	0	0	1
***Medicago sativa* L.**	Fabaceae		1	0	0	1
Melaleuca armillaris* (Sol. ex Gaertn.) Sm. subsp. *armillaris	Myrtaceae		0	0	0	1
***Melaleuca bracteata* F.Muell.**	Myrtaceae		0	0	0	1
***Melaleuca parvistaminea* Byrnes**	Myrtaceae		0	0	0	1
Melaleuca sp.	Myrtaceae		0	0	0	1
***Melia azedarach* L.**	Meliaceae	1b	1	0	0	1
***Metrosideros excelsa* Sol. ex Gaertn.**	Myrtaceae		0	0	0	1
***Mirabilis jalapa* L.**	Nyctaginaceae	1b	1	0	0	1
***Miscanthus sinensis* Andersson**	Poaceae		0	0	0	1
***Monstera deliciosa* Liebm.**	Araceae		0	0	0	1
***Moringa oleifera* Lam.**	Moringaceae		1	0	0	0
Morus alba* L. *var. alba	Moraceae	3	1	0	0	1
***Myoporum tenuifolium* G.Forst.**	Myoporaceae	3	1	0	0	1
***Myriophyllum aquaticum* (Vell.) Verdc.**	Haloragaceae	1b	1	0	0	1
***Myriophyllum spicatum* L.**	Haloragaceae	1b	1	0	0	0
Myrtus communis* L. var. *communis	Myrtaceae		0	0	0	1
***Nandina domestica* Thunb.**	Berberidaceae		0	0	0	1
***Nasturtium officinale* R.Br.**	Brassicaceae	2	1	0	0	1
Nephrolepis cordifolia* (L.) C.Presl var. *cordifolia	Nephrolepidacea e	1b	0	0	0	1
***Nerium oleander* L.**	Apocynaceae	1b	1	0	0	1
***Nicotiana glauca* Graham**	Solanaceae	1b	1	0	0	1
***Nothoscordum gracile* (Aiton) Stearn**	Alliaceae		0	0	0	1
***Ocimum basilicum* L.**	Lamiaceae		0	0	0	1

***Odontonema strictum* (Nees) Kuntze**	Acanthaceae		0	0	0	1
***Oenothera indecora* Cambess.**	Onagraceae		1	0	0	0
***Oenothera jamesii* Torr. & A.Gray**	Onagraceae		1	0	0	0
***Oenothera rosea* L'Hér. ex Aiton**	Onagraceae		1	0	0	0
Oenothera sp.	Onagraceae	3	1	0	0	0
Olea europaea* L. subsp. *europaea	Oleaceae		0	0	0	1
***Opuntia elata* Link & Otto**	Cactaceae	1b	0	0	0	1
***Opuntia ficus-indica* (L.) Mill.**	Cactaceae	1b	1	0	0	1
***Opuntia microdasys* (Lehm.) Pfeiff.**	Cactaceae	1b	0	0	0	1
***Opuntia monacantha* Haw.**	Cactaceae	1b	1	0	0	1
Opuntia sp.	Cactaceae	1a/1b	1	0	0	1
Opuntia stricta* (Haw.) Haw. var. *stricta	Cactaceae	1b	0	0	0	1
Orobanche sp.	Orobanchaceae	1b	0	0	0	1
***Oxalis corniculata* L.**	Oxalidaceae		1	0	0	0
***Pachypodium lamerei* Drake**	Apocynaceae		0	0	0	1
***Pandorea jasminoides* (Lindl.) K.Schum.**	Bignoniaceae		0	0	0	1
Papaver sp.	Papaveraceae		0	0	0	1
Paraserianthes lophantha* (Willd.) I.C.Nielsen subsp. *lophantha	Fabaceae	1b	1	1	1	1
***Parkinsonia aculeata* L.**	Fabaceae	1b	0	0	0	1
***Parthenium hysterophorus* L.**	Asteraceae	1b	0	1	0	0
***Parthenocissus quinquefolia* (L.) Planch.**	Vitaceae		1	0	0	1
***Parthenocissus tricuspidata* Planch.**	Vitaceae		0	0	0	1
***Paspalum dilatatum* Poir.**	Poaceae		1	0	0	0
***Paspalum urvillei* Steud.**	Poaceae		1	0	0	0

Passiflora sp.	Passifloraceae	1b/2	1	0	0	1
***Pennisetum clandestinum* Hochst. ex Chiov.**	Poaceae	1b	1	0	1	1
***Pennisetum purpureum* Schumach.**	Poaceae		1	0	0	1
***Pennisetum setaceum* (Forssk.) Chiov.**	Poaceae	1b	1	0	0	1
***Pennisetum villosum* R.Br. ex Fresen.**	Poaceae	1b	1	0	0	0
***Pereskia aculeata* Mill.**	Cactaceae	1b	1	0	0	1
Persea americana* Mill. var. *americana	Lauraceae		1	0	0	1
***Persicaria capitata* (Buch.-Ham. ex D.Don) H.Gross**	Polygonaceae	1b	1	0	0	1
***Persicaria lapathifolia* (L.) Gray**	Polygonaceae		1	0	0	1
***Petrea volubilis* L.**	Verbenaceae		0	0	0	1
***Phoenix canariensis* Chabaud**	Arecaceae		0	0	0	1
***Phormium tenax* J.R.Forst. & G.Forst.**	Asphodelaceae		0	0	0	1
Phyllostachys sp.	Poaceae		0	0	0	1
***Physalis peruviana* L.**	Solanaceae		1	0	0	1
***Phytolacca dioica* L.**	Phytolaccaceae	3	1	0	0	1
***Phytolacca octandra* L.**	Phytolaccaceae	1b	1	1	0	1
Pinus sp.	Pinaceae	1b/2	1	1	1	1
***Pistia stratiotes* L.**	Araceae	1b	1	0	0	0
***Pittosporum undulatum* Vent.**	Pittosporaceae	1b	1	0	1	1
***Plantago lanceolata* L.**	Plantaginaceae		1	0	0	1
***Plantago major* L.**	Plantaginaceae		1	0	0	1
Platanus sp.	Platanaceae		1	0	0	1
***Plectranthus barbatus* Andrews var. *grandis* (L.H.Cramer) Lukhoba & A.J.Paton**	Lamiaceae	1b	1	0	0	1
***Plectranthus neochilus* Schltr.**	Lamiaceae		0	0	0	1
***Plectranthus ornatus* Codd**	Lamiaceae		0	0	0	1
***Plumbago auriculata* Lam. forma *alba* (Pasq.) T.H.Peng**	Plumbaginaceae		0	0	0	1
Plumeria sp.	Apocynaceae		0	0	0	1

Poa pratensis **L.**	Poaceae		1	0	0	0
Podranea ricasoliana **(Tanfani) Sprague**	Bignoniaceae		0	0	0	1
Polygonum aviculare **L.**	Polygonaceae		1	0	0	0
Polypogon monspeliensis **(L.) Desf.**	Poaceae		1	0	0	0
Pontederia cordata **L. var.** ***cordata***	Pontederiaceae	1b	1	0	0	1
Populus alba **L. var.** ***alba***	Salicaceae	2	0	0	1	0
Populus deltoides **Bartram ex Marshall subsp.** ***deltoides***	Salicaceae		1	0	0	1
Populus nigra **L. var.** ***italica*** **Münchh.**	Salicaceae		0	0	0	1
Populus simonii **Carrière**	Salicaceae		0	0	0	1
Populus sp.	Salicaceae	2	0	1	1	0
Populus x canescens	Salicaceae	2	1	1	1	1
Portulaca oleracea **L.**	Polygonaceae		1	0	0	0
Prosopis sp.	Fabaceae	1b	1	0	0	1
Prunus armeniaca **L.**	Rosaceae		1	0	0	1
Prunus domestica **L.**	Rosaceae		0	0	0	1
Prunus persica **(L.) Batsch var.** ***persica***	Rosaceae		0	0	0	1
Prunus sp.	Rosaceae	1b	0	0	0	1
Psidium guajava **L.**	Myrtaceae		0	0	0	1
Psidium cattleianum **Sabine**	Myrtaceae	1b	0	0	0	1
Punica granatum **L.**	Punicaceae		1	0	0	1
Pyracantha angustifolia **(Franch.) C.K.Schneid.**	Rosaceae	1b	1	0	0	1
Pyracantha coccinea **M.Roem.**	Rosaceae	1b	0	0	0	1
Pyracantha crenulata **(D.Don) M.Roem.**	Rosaceae	1b	1	0	0	0
Pyracantha rogersiana **(A.B.Jacks.) Chitt.**	Rosaceae		1	0	0	0
Pyrus sp.	Rosaceae		1	0	0	1
Quercus agrifolia **Née**	Fagaceae		0	0	0	1
Quercus ilex **L. var.** ***ilex***	Fagaceae		0	0	0	1
Quercus nigra **L.**	Fagaceae		0	0	0	1
Quercus palustris **L.**	Fagaceae		1	0	0	1

***Quercus petraea* L. ex Liebl.**	Fagaceae		0	0	0	1
***Quercus robur* L.**	Fagaceae		1	1	0	1
Quercus sp.	Fagaceae		1	0	1	1
***Quercus suber* L.**	Fagaceae		1	0	1	1
***Raphanus raphanistrum* L.**	Brassicaceae		0	0	0	1
***Rhaphiolepis indica* (L.) Lindl.**	Rosaceae		0	0	0	1
***Rhododendron indicum* Sweet**	Ericaceae		0	0	0	1
***Rhus succedanea* L.**	Anacardiaceae		1	0	0	0
Ricinus communis* L. var. *communis	Euphorbiaceae	2	1	0	1	1
***Robinia pseudoacacia* L.**	Fabaceae	1b	1	0	1	1
Rosa sp.	Rosaceae		0	0	0	1
***Rosmarinus officinalis* L.**	Lamiaceae		0	0	0	1
***Rubus cuneifolius* Pursh**	Rosaceae	1b	0	1	1	0
***Rubus fruticosus* L.**	Rosaceae	2	1	1	0	0
Rubus sp.	Rosaceae	1b/2	1	1	1	1
Rumex sp.	Polygonaceae	1b	1	0	0	1
***Rumex usambarensis* (Dammer) Dammer**	Polygonaceae	1b	0	0	0	1
Ruscus sp.	Asparagaceae		0	0	0	1
***Sagina procumbens* L.**	Caryophyllaceae		1	0	0	0
Salix babylonica* L. var. *babylonica	Salicaceae		1	0	0	1
***Salix caprea* L.**	Salicaceae		1	0	0	0
Salix sp.	Salicaceae		0	0	1	1
***Salsola kali* L.**	Chenopodiaceae	1b	1	0	0	1
***Salvia leucantha* Cav.**	Lamiaceae		0	0	0	1
***Salvinia molesta* D.S.Mitch.**	Salviniaceae	1b	1	0	0	1
Sambucus nigra* L. var. *nigra	Caprifoliaceae	1b	1	0	0	1
***Sansevieria trifasciata* Prain**	Asparagaceae		0	0	0	1
***Schefflera actinophylla* (Endl.) Harms**	Araliaceae		0	0	0	1
***Schefflera arboricola* (Hayata) Merr.**	Araliaceae		0	0	0	1
***Schinus molle* L.**	Anacardiaceae		1	0	0	1
Schinus	Anacardiaceae	3	1	0	0	1

terebinthifolius **Raddi**						
Schizolobium parahyba **(Vell.) Blake**	Fabaceae		0	0	0	1
Schotia brachypetala **Sond.**	Fabaceae		0	0	0	1
Searsia lancea **(L.f.) F.A.Barkley**	Anacardiaceae		0	0	0	1
Senecio tamoides **DC.**	Asteraceae		0	0	0	1
Senna didymobotrya **(Fresen.) H.S.Irwin & Barneby**	Fabaceae	1b	1	0	0	1
Sesbania punicea **(Cav.) Benth.**	Fabaceae	1b	1	1	1	1
Sida rhombifolia **L. subsp.** ***rhombifolia***	Malvaceae		0	0	0	1
Silybum marianum **(L.) Gaertn.**	Asteraceae		1	0	0	0
Sisyrinchium sp.	Iridaceae		1	0	0	0
Solanum jasminoides **J. Paxton**	Solanaceae		0	0	0	1
Solanum laxum **Spreng.**	Solanaceae		0	0	0	1
Solanum mauritianum **Scop.**	Solanaceae	1b	1	1	1	1
Solanum nigrum **L.**	Solanaceae		1	0	0	1
Solanum pseudocapsicum **L.**	Solanaceae	1b	1	0	0	0
Sonchus oleraceus **L.**	Asteraceae		1	0	0	1
Sorghum halepense **(L.) Pers.**	Poaceae	2	1	0	0	0
Spartium junceum **L.**	Fabaceae	1b	1	0	0	1
Sphaeropteris cooperi **(Hook. ex F.Muell.) R.M.Tryon**	Cyatheaceae		0	0	0	1
Spiraea cantonensis **Lour.**	Rosaceae		0	0	0	1
Spirea sp	Rosaceae		0	0	0	1
Stellaria media **(L.) Vill.**	Caryophyllaceae		0	0	0	1
Strelitzia alba **(L.f.) Skeels**	Strelitziaceae		0	0	0	1
Strelitzia nicolai **Regel & Körn.**	Strelitziaceae		0	0	0	1
Syagrus romanzoffiana **(Cham.) Glassman**	Arecaceae		0	0	0	1

***Synadenium cupulare (Boiss.)* L.C.Wheeler**	Euphorbiaceae		0	0	0	1
***Syngonium podophyllum* Schott**	Araceae		0	0	0	1
Syzygium cordatum* Hochst. ex C.Krauss subsp. *cordatum	Myrtaceae		0	0	0	1
***Syzygium jambos* (L.) Alston**	Myrtaceae	3	1	0	0	1
***Syzygium paniculatum* Gaertn.**	Myrtaceae		1	0	0	1
***Tagetes minuta* L.**	Asteraceae		1	0	0	0
***Tamarix ramosissima* Ledeb.**	Tamaricaceae	1b	1	0	0	0
Tamarix sp.	Tamaricaceae	1b	1	0	0	1
***Taxodium distichum* (L.) Rich.**	Cupressaceae		0	0	0	1
Tecoma stans* (L.) Juss. ex Kunth var. *stans	Bignoniaceae	1b	0	0	0	1
***Tetrapanax papyriferus* (Hook.) C.Koch**	Araliaceae		0	0	0	1
***Thunbergia alata* Bojer ex Sims**	Acanthaceae		0	0	0	1
***Tipuana tipu* (Benth.) Kuntze**	Fabaceae	3	1	0	0	1
Torilis arvensis* (Huds.) Link subsp. *heterophylla* (Guss.) Thell. var. *heterophylla	Apiaceae		1	0	0	0
***Trachelospermum jasminoides* Lem.**	Apocynaceae		0	0	0	1
***Tradescantia fluminensis* Vell.**	Commelinaceae	1b	0	0	0	1
***Tradescantia pallida* (Rose) D.R.Hunt**	Commelinaceae		0	0	0	1
Tradescantia sp.	Commelinaceae	1b	1	0	0	1
***Tradescantia zebrina* Bosse**	Commelinaceae	1b	0	0	1	1
***Tragopogon dubius* Scop.**	Asteraceae		1	0	0	0
***Tribulus terrestris* L.**	Zygophyllaceae		1	0	0	1
Trichilia emetica* Vahl subsp. *emetica	Meliaceae		0	0	0	1
Trifolium	Fabaceae		0	0	0	1

angustifolium L. var. *angustifolium*						
Trifolium sp.	Fabaceae		0	0	0	1
Triticum spp.	Poaceae		0	0	0	1
Tropaeolum majus L.	Tropaeolaceae		1	0	0	1
Ulmus parvifolia Jacq.	Ulmaceae		0	0	0	1
Urtica urens L.	Urticaceae		0	0	0	1
Verbascum virgatum Stokes	Scrophulariaceae		0	0	0	1
Verbena bonariensis L.	Verbenaceae	1b	1	0	0	1
Verbena officinalis L.	Verbenaceae		1	0	0	0
Verbena rigida Spreng.	Verbenaceae	1b	1	0	0	0
Verbesina encelioides (Cav.) Benth. & Hook.f. ex A.Gray subsp. *encelioides*	Asteraceae		0	0	0	1
Viburnum odoratissimum Ker Gawl.	Viburnaceae		0	0	0	1
Viburnum tinus L.	Viburnaceae		0	0	0	1
Vicia sp.	Fabaceae		0	0	0	1
Vinca major L.	Apocynaceae	1b	1	0	0	1
Vitis sp.	Vitaceae		1	0	0	1
Washingtonia robusta H.Wendl.	Arecaceae		0	0	0	1
Westrigia sp.	Lamiaceae		0	0	0	1
Westringia fruticosa (Willd.) Druce	Lamiaceae		0	0	0	1
Wigandia caracasana Kunth	Hydrophyllaceae		1	0	0	0
Wigandia urens (Ruíz & Pav.) Kunth var. *caracasana* (Kunth) Gibson	Hydrophyllaceae	3	1	0	0	1
Wisteria floribunda (Willd.) DC.	Fabaceae		0	0	0	1
Xanthium spinosum L.	Asteraceae	1b	1	0	0	0
Xanthium strumarium L.	Asteraceae	1b	1	1	1	1
Yucca sp.	Asparagaceae		0	0	0	1